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AN INVESTIGATION TO DETERMINE THE PRODUCIBILITY OF A 3-D BRAIDER AND BIAS DIRECTION WEAVING LOOM

Cooperative Agreement NCC1-128

FINAL REPORT

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September 1991

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Note: Three-dimensional pictorials were drawn using AUTOCAD, which is not a true 3-D modeling program. Therefore, some detail is lost or distorted in those pictorial drawings.

ABSTRACT

The development of prototype machines for the production of generalized braid patterns is described. Mechanical operating principles and control strategies are presented for two prototype machines which have been fabricated and evaluated. Both machines represent advances over current techniques for forming composite material preforms by enabling near ideal control of fiber orientation. Further, they overcome both the lack of general control of produced fiber architectures and the complexity of other weaving processes that have been proposed for the same purpose.

One prototype, the modified Farley braider, consists of an array of turntables which can be rotated 90^0 and returned, and hence can form tracks in the X and Y axis. Yarn ends are transported about the surface formed by the turntables using motorized tractors. These tractors are controlled using an optical link with a control circuit and host computer. The tractors are powered though electrical contact with the turntables. The necessary relative motions are produced by a series of linear tractor moves combined with a sequence of turntable rotations. The movement of the tractors about the surface causes the yarns to produce the desired braiding pattern.

The second device, the shuttle plate braider, consists of a braiding surface formed by an array of square elements, each separated from its neighbor by a gap. Beneath this surface lies a shuttle plate, which reciprocates first in one axis and then in the other. As this movement takes place, yarn carrying shuttles engage and disengage the plate by means of solenoid activated pins. By selective engagement and disengagement, the shuttles can move the yarn ends in any desired pattern, forming the desired braid. Control power, and control signals, are transmitted from the electronic interface circuit and host computer, via the braiding surface through electrical contact with the shuttles. Motive power is proved to the shuttles by motion of the shuttle plate, which is passively driven using pneumatic rams. Each shuttle is a simple device that uses only a solenoid to engage the plate and is independently controllable. When compared with each other, the modified Farley braider has the advantage of speed, and the shuttle plate braider the advantages of mechanical and control simplicity.

I. Introduction.

The work described here was begun in August 1988 as a preliminary study of the feasibility of developing machines to generate three dimensional braided and woven materials, and was later focused on the development of braiding techniques, as embodied in the hardware and control schemes of two small demonstration machines.

As initially conceived, the study was to assess the technical feasibility of various procedures for both weaving and braiding of composite preforms of very general types. In the case of weaving, the ultimate goal was to produce multi-layer fabric having bias direction yarns inserted at any layer and in any direction, and, further, to be produced with a completely variable degree of crimping. For braiding, the standard was a fully braided structure in which the braid pattern was not an inherent feature of the production process but was subject to complete control. The ultimate goal of the whole effort was to develop a systematic, rational approach to the development of prototype machines to demonstrate the feasibility of the processes.

Subsequent to starting the study, it was determined by the sponsor that structures having a relatively small fraction of crimped yarns would be of primary importance. Also, it became apparent during the course of the study that any of the woven structures were essentially equivalent to stitched assemblies of individual layers when the proportion of crimped fibers fell to a

level required only to hold the assembly together. Given promising results from stitching procedures being considered elsewhere, it was agreed to reduce the attention given to weaving and that braiding should be the focus of any work to follow. However, the initial phase yielded some interesting results, all of which were reported earlier and explored in the student project report which was included as an appendix to the December 1988 interim report and will not be discussed further here. It is, however, included in Appendix H of this report.

The results, then, of the investigative work which has been performed consist of a better understanding of the techniques involved in 3-D braiding and the development of two distinctive methods by which universally variable braids might be made. Two small demonstration machines have been produced and operated, showing that any desired 3-D braid pattern can be produced using either scheme, both of which have unique advantages and disadvantages. The discussion which follows will provide general information about the results of the subject investigation. It also describes the evaluation of thought that accompanied the development of the prototypes. Detailed descriptions and documentation of the machines are presented in the appendices to this report.

II. GENERAL CONSIDERATION OF BRAIDING AND WEAVING

No clear, generally accepted definition of either braiding or weaving as distinct processes appears to exist. It seems that the classification of a particular process as one or the other depends more on the nature of the machine being used than on the actual nature of the product or process. Materials produced on conventional looms are readily classified as woven products, but the distinction blurs when the process evolves into something similar to the King and Fukuta processes or the NC State University 3-D weaving process.[12] Materials formed by the last two processes are shown in Figures 1 and 2. Still the classification is based more on the machine than on the process and depends upon whether the machines are composed of loom-like or of braider-like elements. However, if the actual interweaving process is considered in formulating a definition, then a different view develops. For instance, the general, ideal braiding process could be thought of as a procedure in which any interwoven structure can be produced by the successive exchange of positions of any of many individual yarns arranged in a spatial array. The validity of this notion as a fundamental definition is supported by the fact that the AYPEX process has been shown to to be theoretically capable of yielding any braided structure.[16] Some of the elementary position changes for this process are shown

in Figure 3. The interweaving is accomplished by the successive exchange of positions of adjacent yarns, hence the name Adjacent Yarn Package EXchange. Any other braiding process can be viewed as a less general procedure in which restrictions are placed upon the possible interchanges that can occur. A conventional 2-D braider, for example, executes a subset of the possible interchanges and this subset is fixed by the mechanical construction of the machine. Conventional weaving consists of a subset of exchanges as illustrated in Figure 4. The shedding operation in weaving is the repeated, simultaneous interchanging of complete rows of yarns. Fill insertion is likewise an exchange of position. The general, ideal braider would be capable of duplicating any of the weaving processes, though, loom-like machines are not capable of approaching the general braiding process. However, a machine capable of implementing the general braiding process would be an inefficient weaver. In fact it likely would be an inefficient alternative to produce any materials for which more specifically optimal machines could be built. This is because the flexibility to produce all possible interchanges would likely result in much redundant capability when applied to the production of a material that requires only a few yarn interchanges. This complexity can be reduced, however, if the goal is to produce materials having a limited range of variation. For example, ordinary looms are built to yield materials of a certain type but are limited to that type.

III. Use of Braiding for Preforms

Major barriers to the use of composites include poor damage tolerance and high costs. A possible cure for these problems is the use of near-net-shape preforms made of textiles. This use has demanded the development of techniques and machinery to produce these preforms. Techniques such as weaving, braiding, stitching, and knitting are all in use to some degree. Figure 5 shows the basic processes used in each case. Automation is increasingly being used to cut costs and to provide specialized shapes to increase damage tolerance and to decrease such problems as delamination.

Braiding as a technique for obtaining desirable preforms has developed for use in situations where special strength properties are needed. It obviously can and has been used in situations where tubular shapes, such as ductwork and tubing are required. Further, serious efforts have been mounted to use braiding to form structural shapes, especially since braiding has the potential to yield nearly ideal strength properties at critical points. However, braiding is not envisioned to be a universal cure-all, and in fact would be a poor choice of techniques for uniform, panel-like shapes. Unfortunately, braiding has not been developed to the same high degree as weaving, stitching and knitting, all of which are common in the textile industry. In fact, most current development of braiding

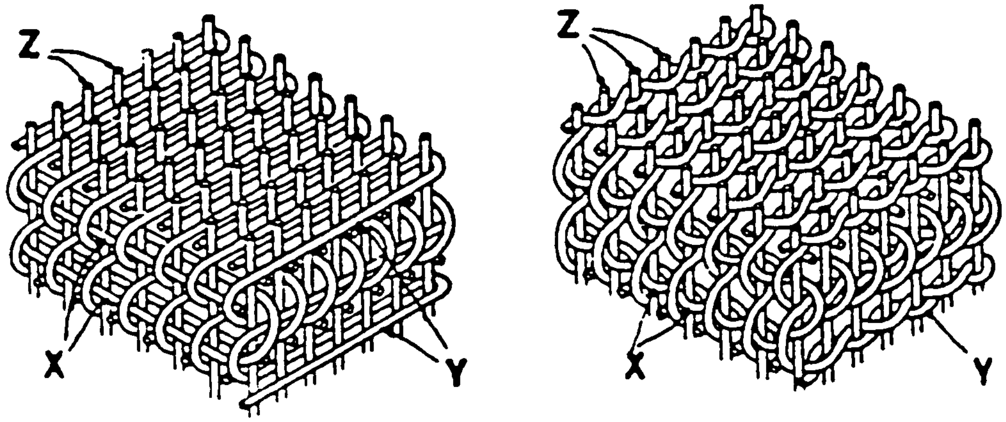


Figure 1: Material of the Type Produced by the Fukuta Braiding Process [12]

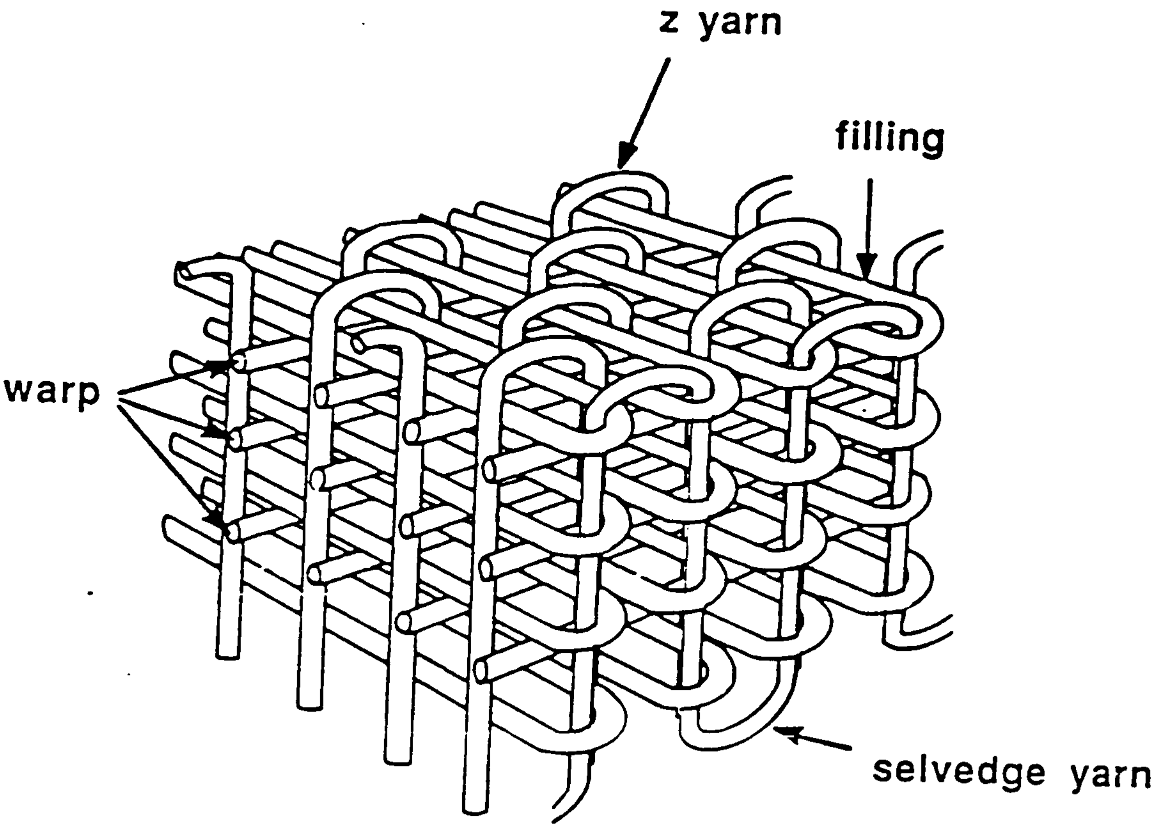


Figure 2: Material of the Type Produced by the NC State University 3-D Weaving Process [12]

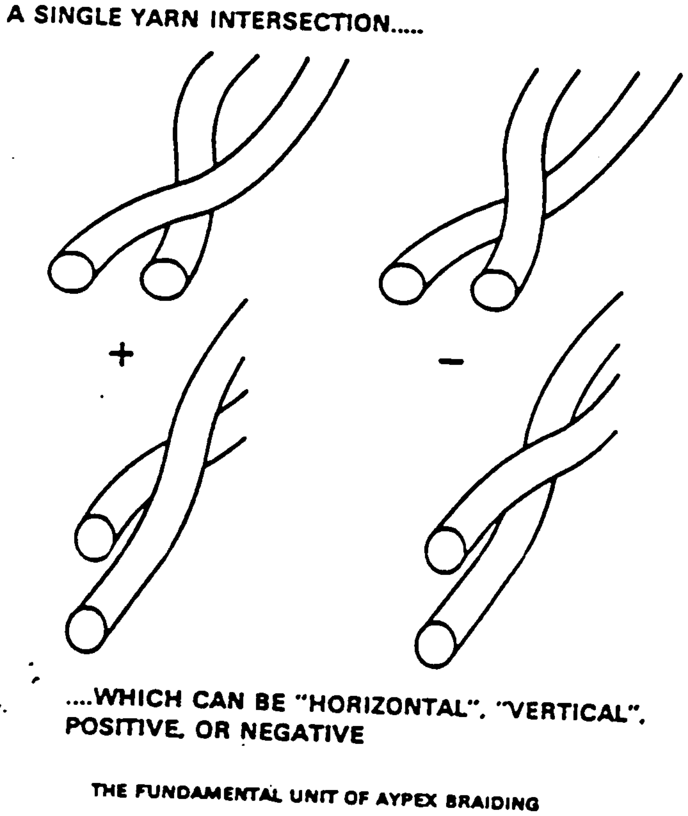


Figure 3: The AYPEX Braiding Process [16]

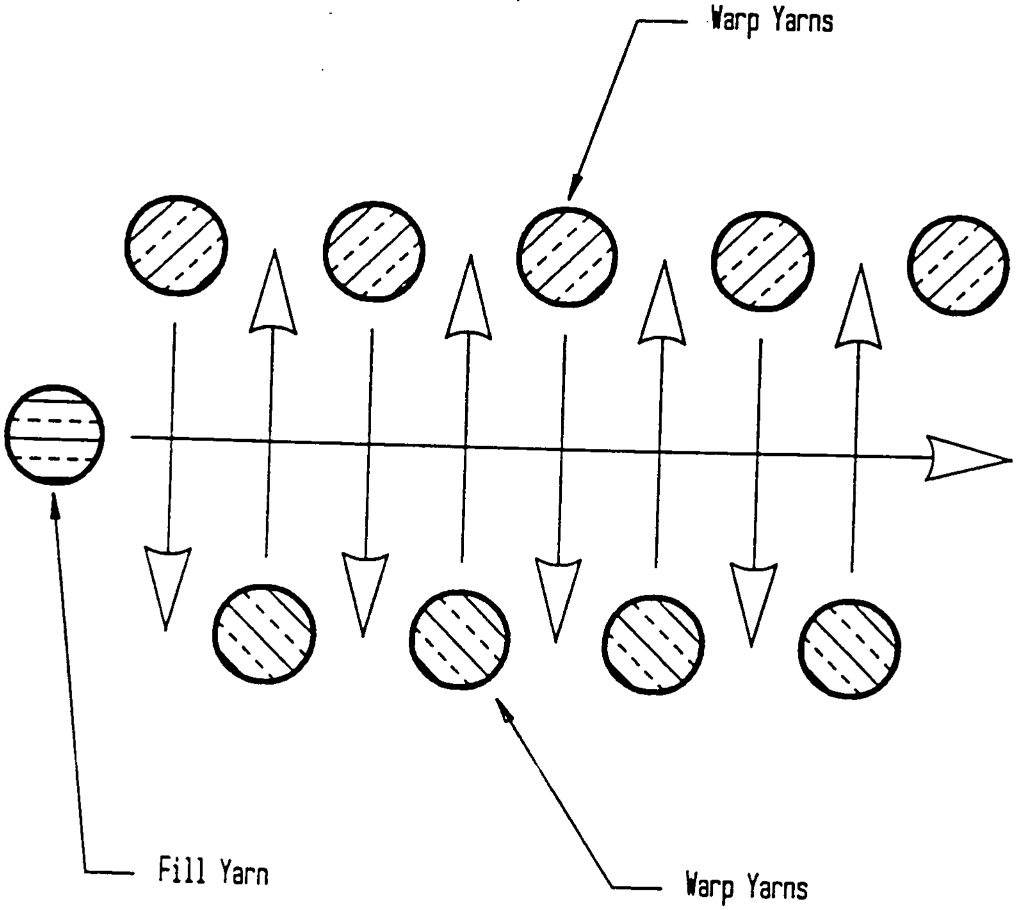
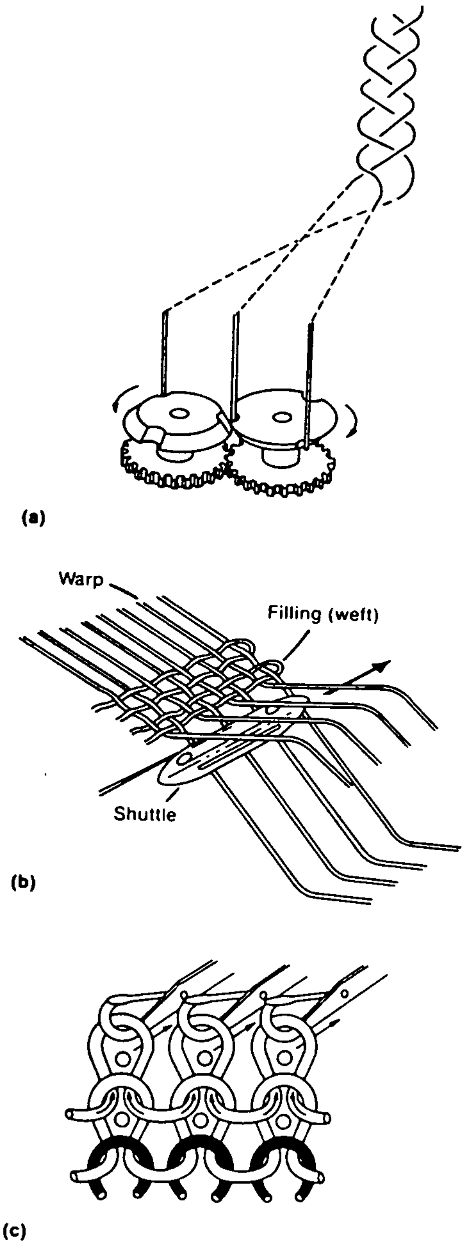


Figure 4: Conventional Weaving Represented as a Series of Position Interchanges



Fabric techniques. (a) Braided. (b) Woven. (c) Knitted

Figure 5: Weaving, Knitting, and Braiding [9]

appears to be occurring in the composite materials industry.

IV. Two - versus - Three Dimensional Braiding.

Two-dimensional braiding is a well-established art. According to F. K. Ko [9], a braid is considered two dimensional if it is formed by two braiding yarn systems, with or without a third laid-in filler yarn. Whenever three or more braiding yarn systems are used to form an integral shape, the braid is considered three dimensional. Thus two-dimensional braiding essentially results in planar shapes, but can produce some three dimensional forms by braiding over mandrels. General 3-D structures, however, must be formed using 3-D techniques. This distinction looses its importance, however, when generalized braiding as discussed in Section II. of this report is considered.

V. The Problem.

As envisioned by the investigator(s) in this study, the problem was to explore the problem of generalized braiding with the aim of identifying feasible processes and developing prototype machines embodying these processes. Further, it was intended to develop, in the course of the investigations of braiding and the fabrication of prototypes, the insight needed to produce a braiding machine of mature design. It was understood that any

particular hardware and control embodiment was not intended to be an optimized approach, but rather an effort to rapidly explore alternatives in the simplest manner possible, in particular, the control strategies.

Four requirements were the principal influences in the development of the designs described later. These were as follows:

1. A completely general braiding capability was to be attained. This general capability required a process that would move any yarn end from any position on the braiding surface to any other position by any prescribed path.

2. The mechanical construction and control requirements had to be practically implementable even in machines of large size.

3. A large number of non-braiding, axial yarns, were to be accommodated.

4. The physical dimensions of the braiding surface were to be minimized, ideally no greater than required to allow the use of yarn packages of one inch diameter.

The approach suggested by the sponsor, and herein called the Farley braider, would be taken as the starting point.

VI. Further Considerations of Braiding and Weaving

An ideal braider would possess only the mechanical complexity needed to control the braiding pattern, yet be capable

of producing generally variable patterns. Most 3-D braiding schemes either achieve simplicity by limiting flexibility or seek flexibility at the expense of complexity. For example, most braiders yield structures having characteristics inherently linked to the process and that cannot be changed, and they therefore have no flexibility at all. Examples are: traditional mechanical braiders such as the one shown in Figure 6, the Florentine Magnaweave scheme, and the two-step braider [4], all of which produce braid patterns that are intrinsic to the process. On the other hand, methods such as the AYPEX procedure possess the necessary flexibility but suffer from complexity in their implementation. This complexity becomes overwhelming when the process is scaled up to produce large sections with full flexibility. Even when the size of the product is modest, the flexibility required to produce a variety of structures requires a great deal of redundant capacity.

Using the ideal braider as a standard, it can be concluded that to minimize complexity, the number of active yarn transport devices should be no greater than the number of braiding yarns, and that one transport device should be sufficient to carry a yarn end completely through a braiding cycle. This fact makes self-powered tractor carriers an attractive approach to the movement of the braiding yarn ends. It would require that the number of transport devices be equal only to the number of braiding yarns, regardless of the pattern, and permits the pattern to be changed

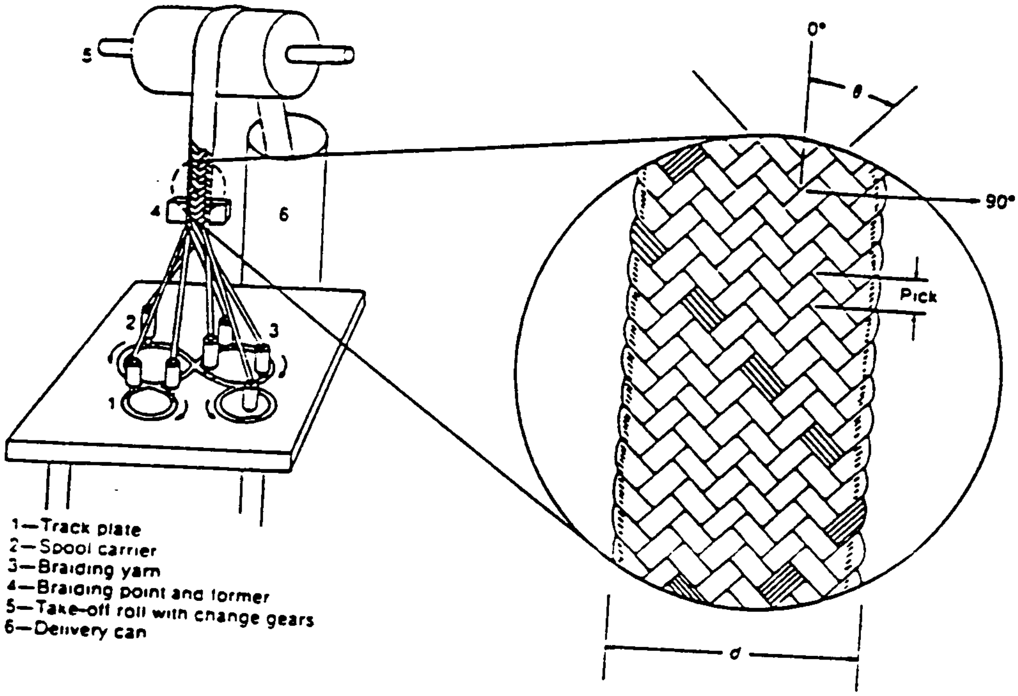


Figure 6: One Example of a Conventional Braider [9]

without additional complexity, provided the transport devices can be individually directed about the braiding surface. This proviso, however, is a significant issue and is addressed further below.

The path followed by the transport devices could either be controlled by the braiding surface or by steering the devices themselves. This path control function is decomposable into two independent components; the guiding and stabilizing of the carrier as it moves, and the separate control of direction. Such an arrangement could be implemented in several ways. The most immediately obvious way to provide the first function would be to use tracks on the braiding surface. Two possibilities exist for implementing the directional control. Either the transport device could incorporate a steering device to route the yarns in the correct direction or the braiding surface could control the direction of motion. The first possibility could result in an entirely passive braiding surface of very simple construction. The braiding surface of the second possibility would be more complicated, with an attendant reduction in complexity at the transport device. Of course, the surface would have to incorporate sensors, power conductors, and the like in either case.

A wide variety of alternative approaches to the implementation of these options were considered. Two approaches were reduced to practice in the form of prototype machines. A

different control strategy was used with each. Either of the control strategies could, with modification, be employed with either of the mechanical approaches. The descriptions of the prototypes that follow incorporate a discussion of the control strategy now implemented on each particular device. The first, the modified Farley braider, is based upon a proposal made by the project sponsor. The second, the shuttle plate braider, was originated in the course of the study. Both approaches make use of a grid of parallel and perpendicular pathways in the braiding surface. The distance between adjacent intersections of orthogonal tracks is referred to in this report as the braiding surface pitch.

VII. The Modified Farley Braider.

General Description.

This embodiment of the concepts behind the ideal braider is illustrated in Figures 7 and 8 and discussed in Appendix B. The braider is made up of an array of 90^0 rotatable turntables and a set of motorized yarn-carrying tractors. In a fully developed braider, there would be one tractor for each yarn-end used to form the braid. Stationary fill yarns, if needed, pass through the braider surface in the space between the turntables. The turntables and tractors communicate with a host computer (PC type) which controls their functioning. The turntables provide the guide needed to support the tractors as they move. The turntables

have only two positions and move as a coordinated unit. (In the original Farley braider, each turntable was capable of being positioned independently of all others, but this capability, while desirable, would require an immense number of actively controlled devices when implemented on a practical scale.) Thus the turntables serve to define a set of parallel paths in the X-axis when in one position and a set of parallel paths in the Y-direction when rotated into the alternate, 90^0 position. The switching action of the turntable array is controlled by the computer, with the switch occurring after each complete set of tractor moves in a given axis. That is, with the turntables set in the X-axis, the tractors are moved as necessary in the X-direction (+ or -). When the tractors become stationary after these moves, the turntables are switched to the Y-axis. The next set of moves of the tractors, all in the Y-direction, then take place. The turntables are then returned to the X-axis orientation, and another set of tractor moves occurs. The switching back and forth of the turntables continues in this alternating manner until the entire braiding program has been executed. Mounted on each turntable is a gear rack, a guide surface, and an optical/electronic signal system, all of which are used to control the tractors.

The yarn-carrying tractor consists of a yarn carrier, an electronic control board, a small d.c. motor, and a gear driven by the motor. Power is conveyed to the motors through contact with

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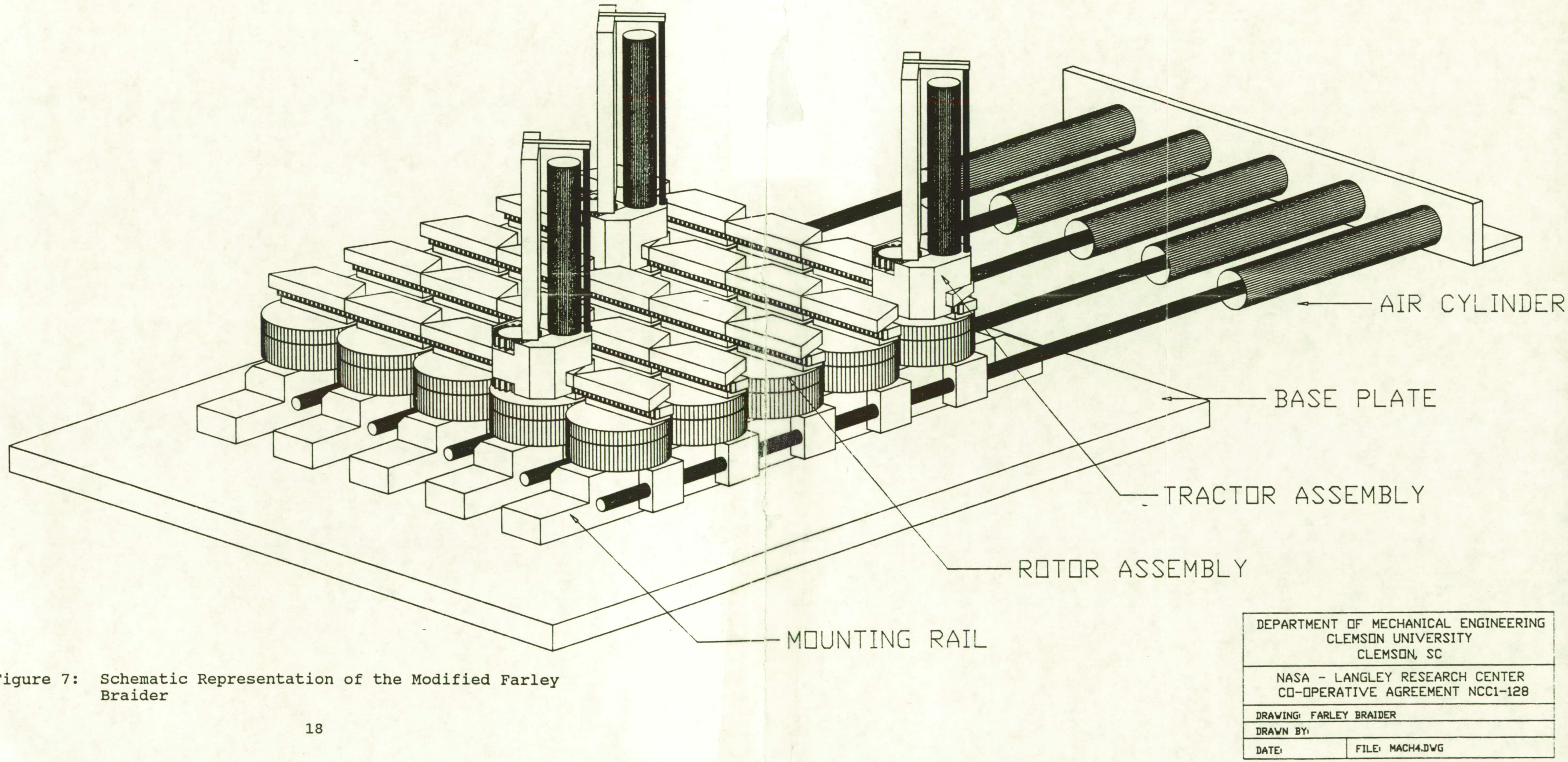

Figure 7: Schematic Representation of the Modified Farley Braider

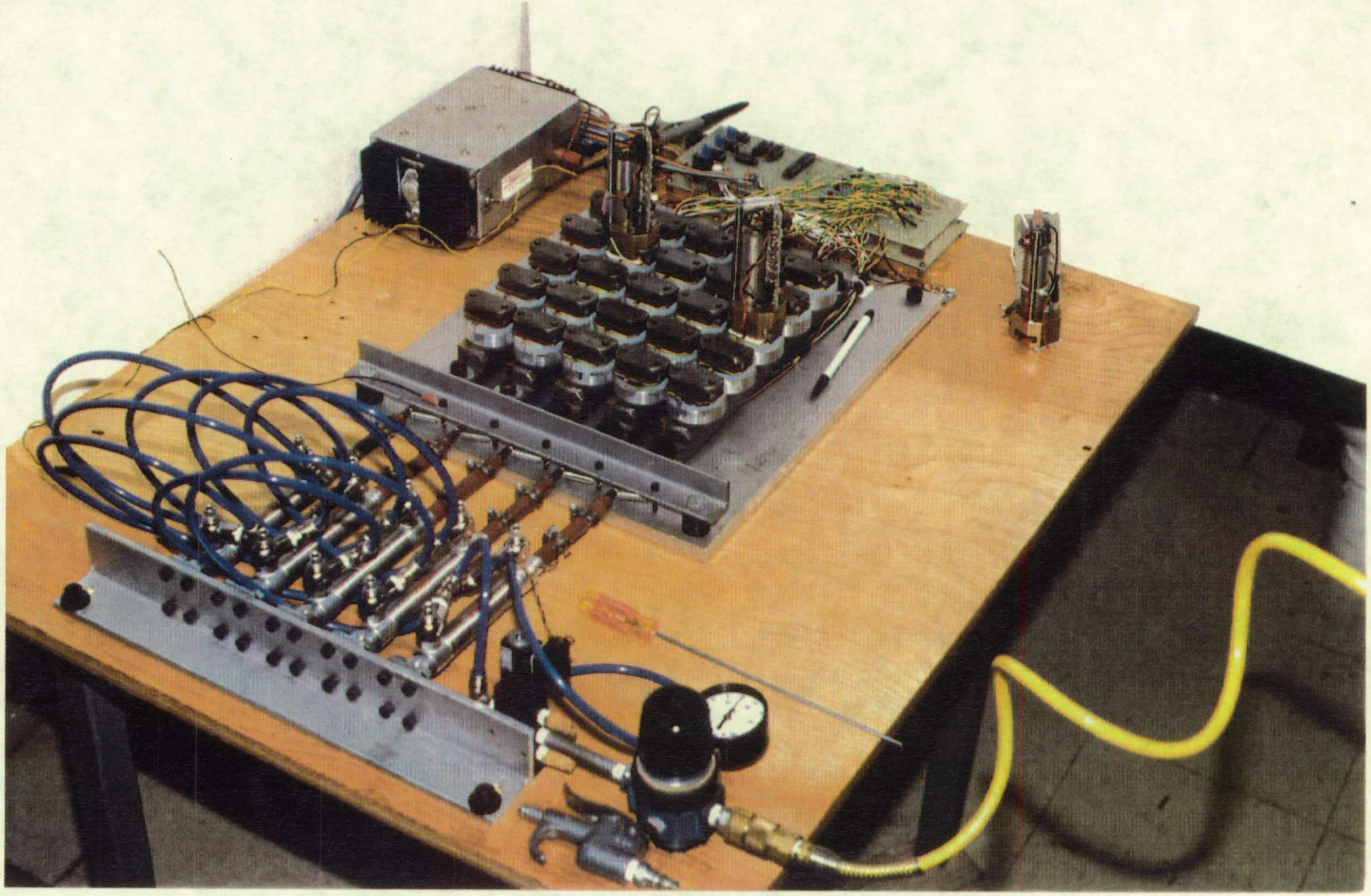

Figure 8: The Modified Farley Braider

electrically isolated conductors incorporated into the turntables. The control computer is used to signal the tractor to begin travel, either forward or backward, and then to cease travel at a given location along that axis, defined as a turntable location specified by the computer. Control signals are sent through optical emitter-detector pairs mounted in the turntables and in the tractors. All the tractors are powered and controlled in this manner.

Operating Sequence.

The sequence of operations is thus, starting with all tractors stationary and all turntables in a specified direction. The computer commands each tractor to begin moving, by turning on that tractor's d.c. motor, in either the + or - direction (or to remain stationary) in that axis. Motion occurs since the motor is attached to a pinion which is riding in the rack attached to the turntables. This movement is nearly simultaneous for all tractors, although, as discussed in the appendix, because of the use of a time multiplexing scheme and the inherent variation in reaction speeds, there are some slight time delays. The computer further signals the control electronics on the turntables to erect stop signals at the location in each tractors path that motion is to stop. This stop signal deenergizes that tractor's motor. Thus the path length of travel of each tractor is specified for this move. When all tractors have completed moving, the turntables are

commanded to rotate a quarter-turn to align to the opposite coordinate axis. In the current prototype, this rotation is accomplished via solenoid controlled valves and pneumatic cylinders. The rotation completed, the next set of move signals is sent to the tractors. These moves are accomplished as before. Then the turntables are commanded to rotate a quarter-turn, in the opposite direction, back to the original axis orientation. At this time the next tractor move occurs. The sequence continues thus, alternating between tractor moves and turntable rotations, until the desired braided shape is completed.

The embodiment of this scheme in the test hardware consists of a 5x5 array, with three tractors. This has proved of sufficient size to test the concepts involved and to allow valid conclusions to be reached. Expansion of the array and the use of additional tractors would be required to scale up the machine to production size. Also, since the tractors are motor-driven and the necessary electrical power is provided through the segmented surface, there is likely to be a practical limit to the number of tractors which can be operated simultaneously with safety.

VIII. The Shuttle Plate Braider.

An alternative to the modified Farley braider discussed above is the shuttle plate braider. This concept is illustrated in Figure 9 and 10 and discussed in detail in Appendix C. In this

device, a segmented surface is provided. The segmentation of this surface provides the guide tracks and support for the yarn carriers, as well as a surface through which to transmit control signals. Riding on this surface are the yarn carrying shuttles, one for each active yarn end. Non-moving yarn ends are threaded up through the segmented surface, one in the middle of each square segment. Unlike the tractors of the first scheme, the shuttles have no motors and therefore are unable to provide their own motive power. However, since the grid system is non-moving, the system is less complex than for the first scheme.

Rather, motive power to the shuttles is provided by a shuttle plate which moves beneath the segmented surface. Control is exercised via computer (PC type). In each shuttle there is a solenoid activated pin which can be extended or retracted on command. If a particular shuttle is to move, it is signaled to extend the pin and lock into the shuttle plate. The shuttle plate is instructed to move in a given direction, via electrical relay and solenoid-actuated valves which control pneumatic cylinders. These cylinders push against the shuttle plate or retract, causing the plate to move in the ordered direction. The shuttle plate moves sequentially in orthogonal directions, first forward then back in the X-direction, then forward and back in the Y-direction. At any given time those shuttles to be moved in the direction of shuttle plate motion are signaled to extend their solenoid pins as described above (See Figure 11). These pins latch into the

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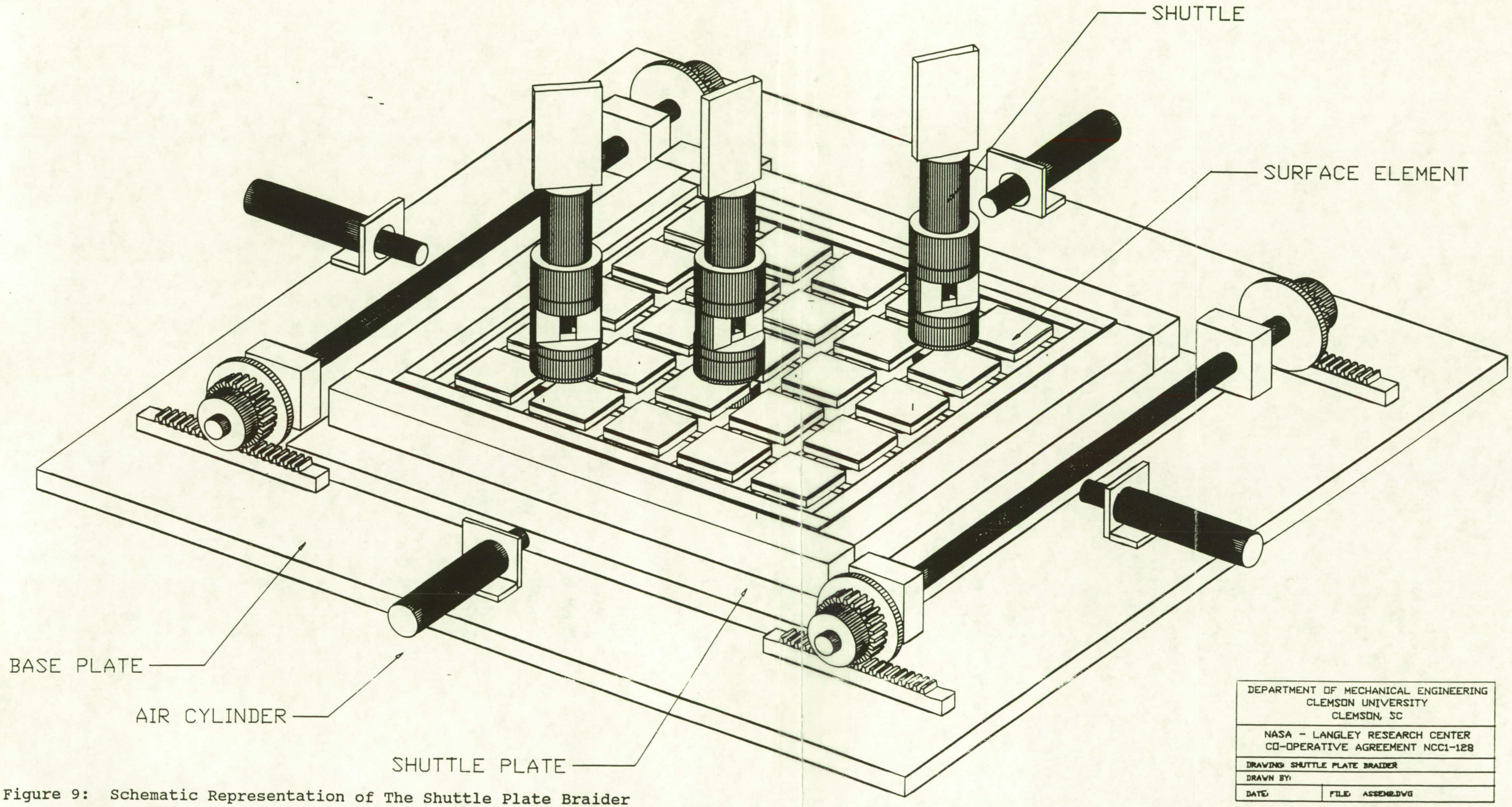

Figure 9: Schematic Representation of The Shuttle Plate Braider

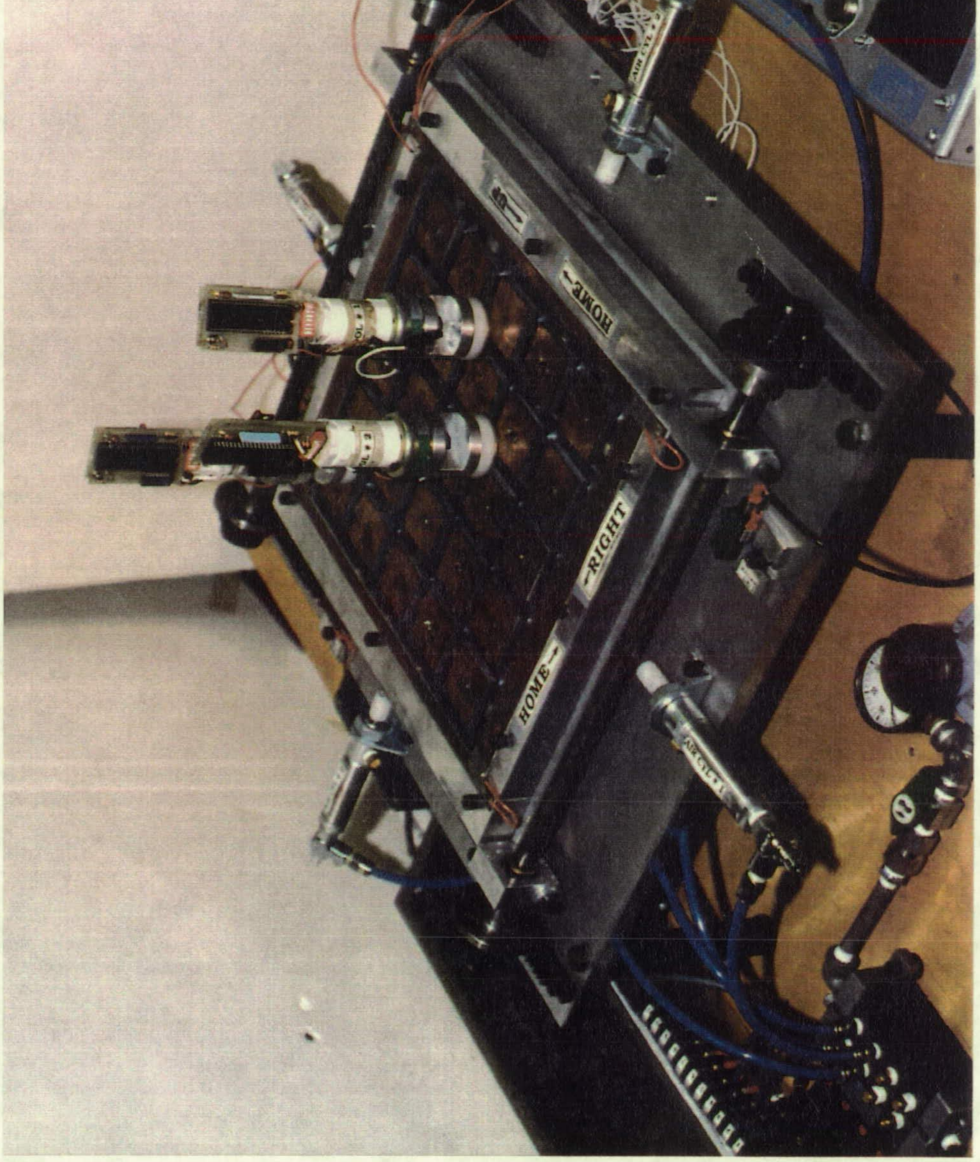

Figure 10: The Shuttle Plate Braider

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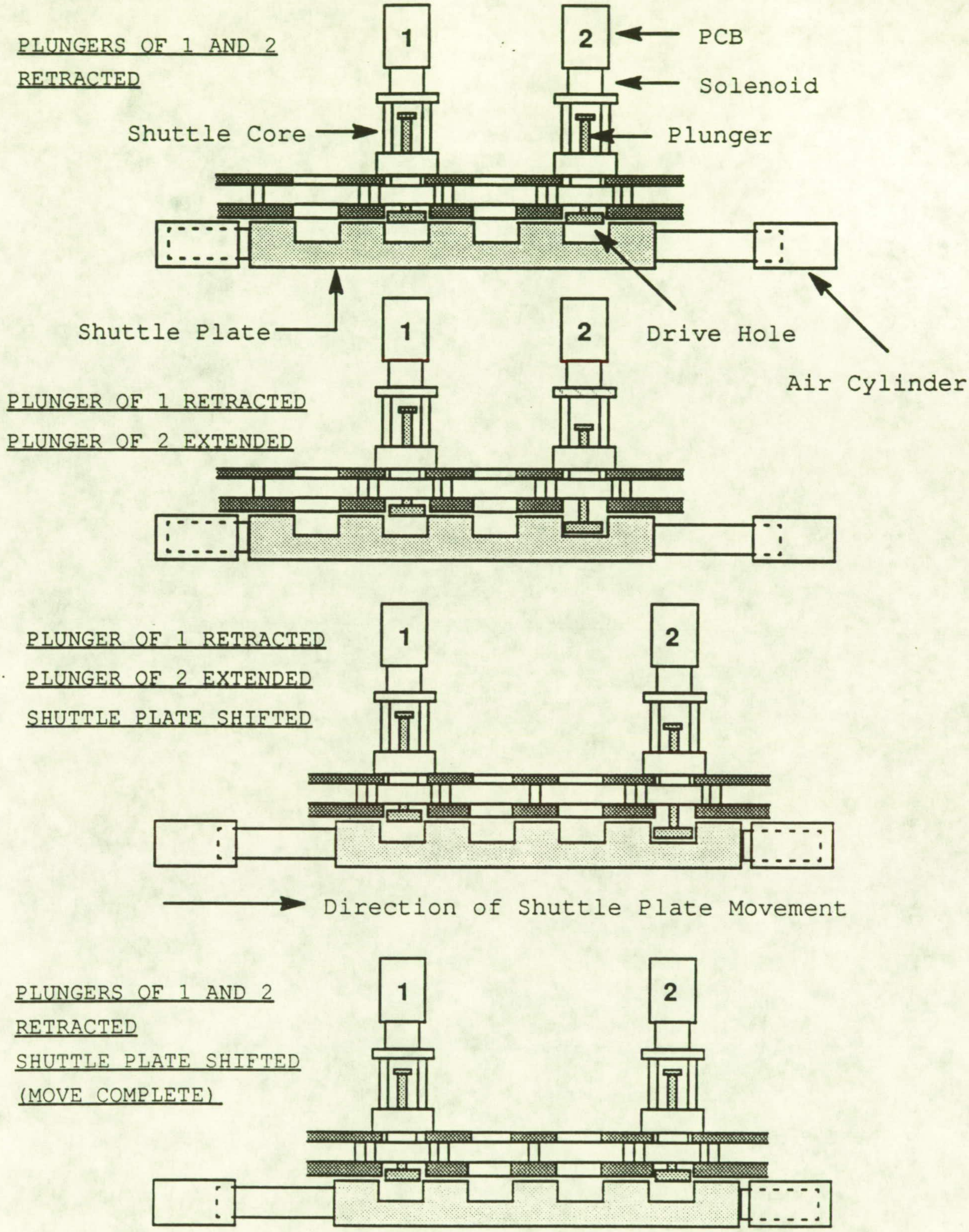

Figure 11: Schematic Representation of Shuttle Plate Operation

shuttle plate and cause the shuttles to move with the plate for that segment of the shuttle plate motion. In this fashion and by selectively engaging individual shuttles any pattern of yarn interlacing can be achieved.

Both power and control signals are transmitted via the segmented braiding surface. This is accomplished by electrically separating the top and bottom faces of the segmented surface, providing two conductors to the shuttles. As currently implemented, each shuttle is assigned a unique address. By encoding control signals with the address corresponding to individual shuttles, each shuttle can be separately controlled. This independent control permits the control flexibility needed to accomplish the aim of braiding completely general yarn structures.

An asynchronous transmitter/receiver integrated circuit chip is used to facilitate communications between the shuttles and the computer. The communications can be expanded readily to include information on yarn tension, fault detection, and the like.

At present, a surface of 5x5 segments and three shuttles has been built. The number of shuttles which can be carried and controlled is very large, limited only by the number of grid intersections available on the braiding surface. Also, enlarging the braiding surface can be readily accomplished by building

surface modules which can be assembled side-by-side into larger surfaces of any form.

IX. Comparisons.

The two braiders discussed both accomplish truly generalized braiding, both in theory and as reduced to practice, in that they are both capable of moving any yarn end from any endpoint to any other endpoint by any practical path specified by the programmer. To the investigator's knowledge, this has not been practically achieved before. The real significance of this accomplishment is that desired braids which have not been achievable in the past can be made.

Comparing the two braiders against each other, as opposed to comparing against other braiding techniques, the following advantages and disadvantages have been determined through operation of the two prototypes in the laboratory.

The shuttle plate braider is a very simple design from a mechanical viewpoint, and its control requirements are as simple as they can be made, since all that is required are simple on/off commands. Further, all the power needed to move the shuttles is derived from the shuttle plate, and thus little power is needed for the shuttles themselves. The modified Farley braider does not have this simplicity, but it does have the advantage of speed for braiding patterns which require numerous long length moves of the

yarn carriers. In addition, while at any given time all the yarn carriers of the modified Farley braider must move along a given axis, some can be moving in the forward direction while others are moving in the reverse direction. Of course, this speed advantage diminishes as the average move length of a yarn carrier becomes shorter in complete patterns. A first effort to quantify this speed difference is provided in Appendix G of this report.

For the modified Farley braider there is a non-trivial concern regarding the timing and synchronization of moves between yarn carriers, especially as the number of carriers increases. This concern could force the use of more complicated devices, such as stepper motors, and "neighbor proximity detectors." The shuttle plate braider does not have this timing difficulty, since all shuttle moves are automatically synchronized.

Although both braiders transmit power to the yarn carriers via the braiding surface, the need for such power is significantly different in kind. The shuttle plate braider needs power on the surface to engage the solenoid in each shuttle. As currently implemented, this power is held continually to keep any given solenoid engaged. If several solenoids are activated at the same time, this would require high currents on the surface. However, there are several ways to overcome this difficulty in a scaled up version of the shuttle plate braider. These include such options as using mechanical latching and momentary currents to engage the latch. For the modified Farley braider, the motors must be

powered continually. Thus the current, of necessity, must increase as the number of moving yarn carriers increases. There is no simple solution to this dilemma. Finally, as the size of the braiders is scaled up to practical applications, addition difference would be evident. The shuttle plate braider scales up readily, since the control problem remains the same no matter the size of the braider. Since the control of long moves is inherently more difficult, and because of the timing difficulties discussed above, scale up of the modified Farley braider would be more difficult. The size of the tractors used in the modified Farley braider was dictated by several factors, which included the size of suitable motors, the choice of gear pitch sufficiently course to permit use of an interrupted rack, and an estimate of the overall size needed to tolerate expected misalignmnents. It is felt the surface pitch used, approximately 2 inches, is the smallest that can be practically implemented without the need for impractical precision. As it is, the precision of alignment and fit are about what is usually found in production braiders and the machine is very temperamental.

In its favor, it should be noted that the modified Farley braider might more easily be implemented on an upwardly curved surface. Use of such a surface would reduce the size of the braiding surface needed to control braid angles. However, such an approach would complicate the design significantly. For example, the turntables of the modified Farley braider would have to be of

unequal size or rotate through unequal angles, depending upon location.

Finally, set up and operation of the shuttle plate braider is much easier and more reliable, as discovered in operations to date. However, either braider could be applied to special or short-run production items, since such situations could not justify the development of special, dedicated machines. In the case of large, mass-production runs, such expenditures could be justified. Of course, some products, even if to be mass produced, might require the flexibility offered by the approach described for these two braiders.

X. Future Directions.

There are additional improvements and refinements which can be made to the two braiders, as well as additional research directions to pursue, should this be desirable.

It should be noted that larger shuttles or yarn-carrying tractors would be much easier to make work. Future work should explore the actual limitations on size. However, larger sizes would obviously result in large braiding surfaces which would be a significant disadvantage.

Both communication schemes used to control the two braiders are novel and work well. Further, either scheme, with

modifications, could have been adapted for either braider. However, there are other interesting and useful communications techniques, such as long distance optics (infrared) or radio frequency devices, which were not explored and might prove very useful.

Other improvements and refinements include revision to the time-multiplexing scheme of controlling the tractors on the modified Farley braider, by either adjusting frequencies to a higher level or eliminating the multiplexing altogether. This will simplify and speed up control command sequencing, allowing better control of multiple tractors. Another alternative would be to incorporate a microprocessor into each modular section of the braider. In this way modular sections of the braider could be strung together, each working with its own processor, eliminating the need for the host controller to deal with the larger multiplexing problem. Neither the shuttle plate nor the modified Farley braider have any form of collision avoidance built into the yarn carriers. At present, good programming practice is the only protection against crashes. The shuttle plate braider currently "half-steps" through its motions. It is possible to make full "steps" (one entire grid division), doubling the speed of the shuttle movement, and hence the braiding process. The shuttle pins are currently held engaged in the shuttle plate by energized solenoids. It may be better to have mechanically latching solenoids, so the length of time that current must be on the

braiding surface can be reduced.

Additional research should be conducted into the question of "beat-up." Manual beat-up was used in the current study. Enhanced communications, to include information feedback to the host computer, will be necessary and has not been pursued.

There may be advantages to using advanced devices, such as linear (2-D) stepper motors, but these were not explored, in the interest of simplicity of the investigation. Such advanced devices represent a significant investigative effort in themselves, but might prove very useful in future braiders.

Finally, no consideration has been given to the effect on the electrical and electronic components of using conductive braiding yarns.

XI. Summary.

A successful attempt to develop and implement generalized, three dimensional braiding has been accomplished. Not only has the study successfully achieved this braiding, but two practical schemes for implementation have been designed, built, and tested. Thus the ideas have been successfully reduced to practice. No attempt has been made to achieve the best refinement of the schemes developed. Both schemes, as implemented, work to produce the motions necessary, with a reasonable level of control exercised, to produced any desired braiding motion. Each scheme

has its advantages and disadvantages. However, the shuttle plate braider offers the greater immediate promise because of its mechanical simplicity and ease of control, especially when scaled up to practical dimensions.

Appendix A:

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Appendix B:

The Modified Farley Braider
(Detailed Description)

The modified Farley braider is shown photographically below in Figure B.1 and schematically in Figure B.2. Selected details are shown in additional figures in this appendix, with other drawings and photographs given in Appendices E and F.

The Farley braider, as implemented, consists of a braiding surface formed by an array of turntables, each capable of a 90^0 rotation. Each turntable has mounted on its top surface a section of track, a conducting strip, and an optical emitter/detector pair. When the turntables are oriented in one direction, the track segments form a series of parallel, straight tracks that can be negotiated by self-powered yarn carriers. When the turntables are oriented in the other possible direction (rotated 90^0 from the first position) a series of parallel tracks are formed at 90^0 to the first arrangement. By alternately positioning the track segments in the two positions and causing the carriers to move along the tracks as appropriate in each position, yarn ends can be conveyed from any point on the braiding surface to any other. By exercising simultaneous control over a number of individual carriers, a braided structure can be formed. Additional non-moving yarns can further be installed vertically through the braiding surface and thus can be braided into the finished product

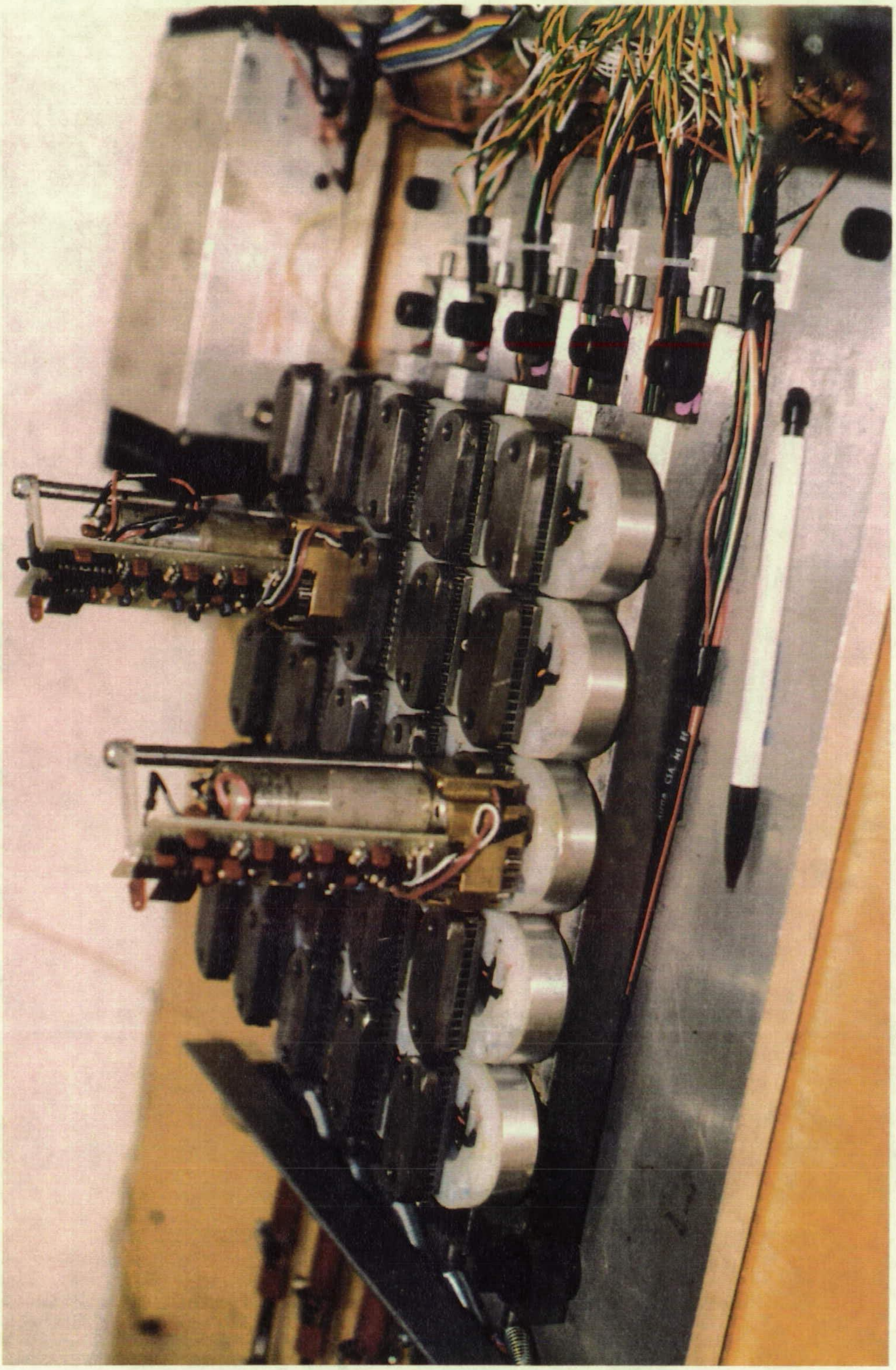


Figure B.1: The Modified Farley Braider

FOLDOUT FRAME 1.

FOLDOUT FRAME 2.

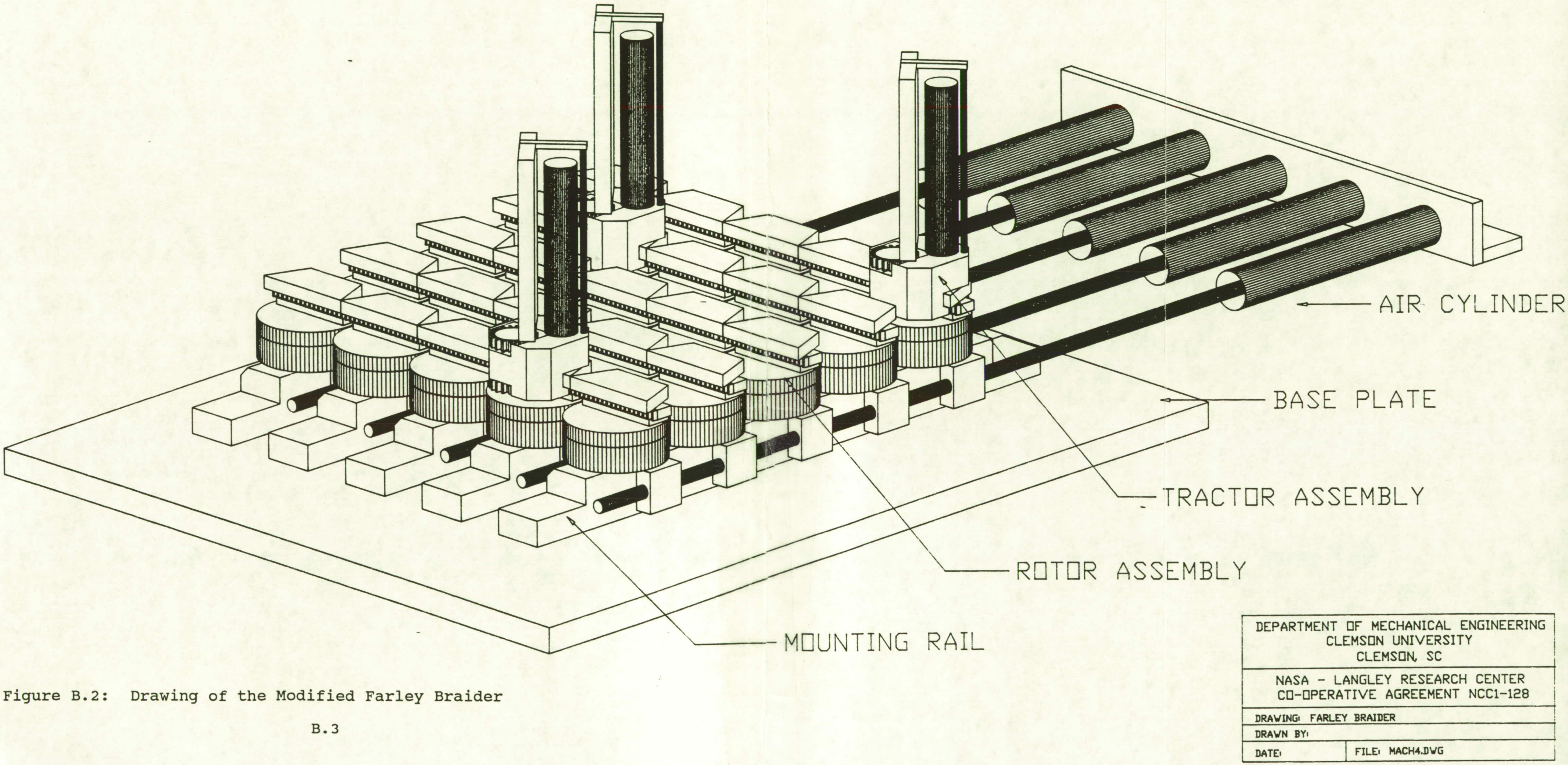


Figure B.2: Drawing of the Modified Farley Braider

as filler yarns.

The yarn carrying tractor is shown in Figures B.3 and B.4. It consists of a body, machined to fit the track segments mounted on the turntables. The body is further machined to mount a small d.c. motor with attached reduction gear, and a drive gear assembly. Also mounted on the body are the electronic control board, and the yarn bobbin. The output shaft of the motor is coupled to a gear train which engages a rack mounted on the braiding surface. By energizing the motor in one rotational direction, the tractor will advance linearly in one axis. By causing the motor to rotate in the opposite hand, the tractor will retreat in that same axis. Of course, speed of advance or retreat depends upon the rotational speed of the motor and the gear ratio.

The control circuitry, mounted on a printed circuit board affixed to the top of the tractor body, is shown schematically in Appendix E. By suitable use of optical emitters and detectors, the tractor motor is instructed to be off, or to energize in either the clockwise or counterclockwise direction. Once energized, the motor remains energized until it receives a signal to turn off (stop). The motor cannot be reversed without receiving a stop signal first. The power needed to drive the tractor motors, as well as the control signals to a tractor, are all transmitted via the braiding surface, which is electrically conductive. Thus the tractors need have no external electrical conductors and are free to move without fear of entangling

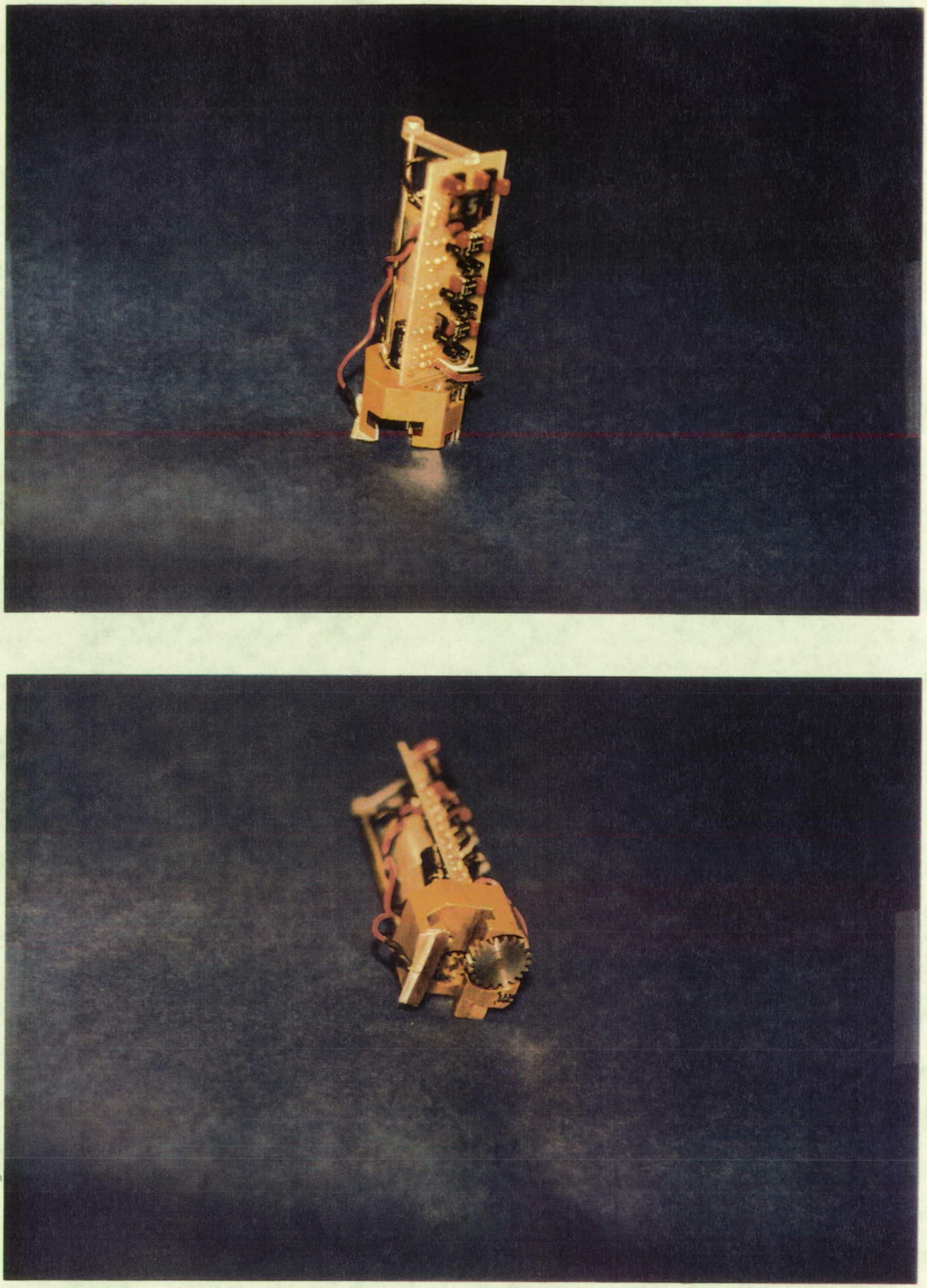


Figure B.3: The Yarn-Carrying Tractor

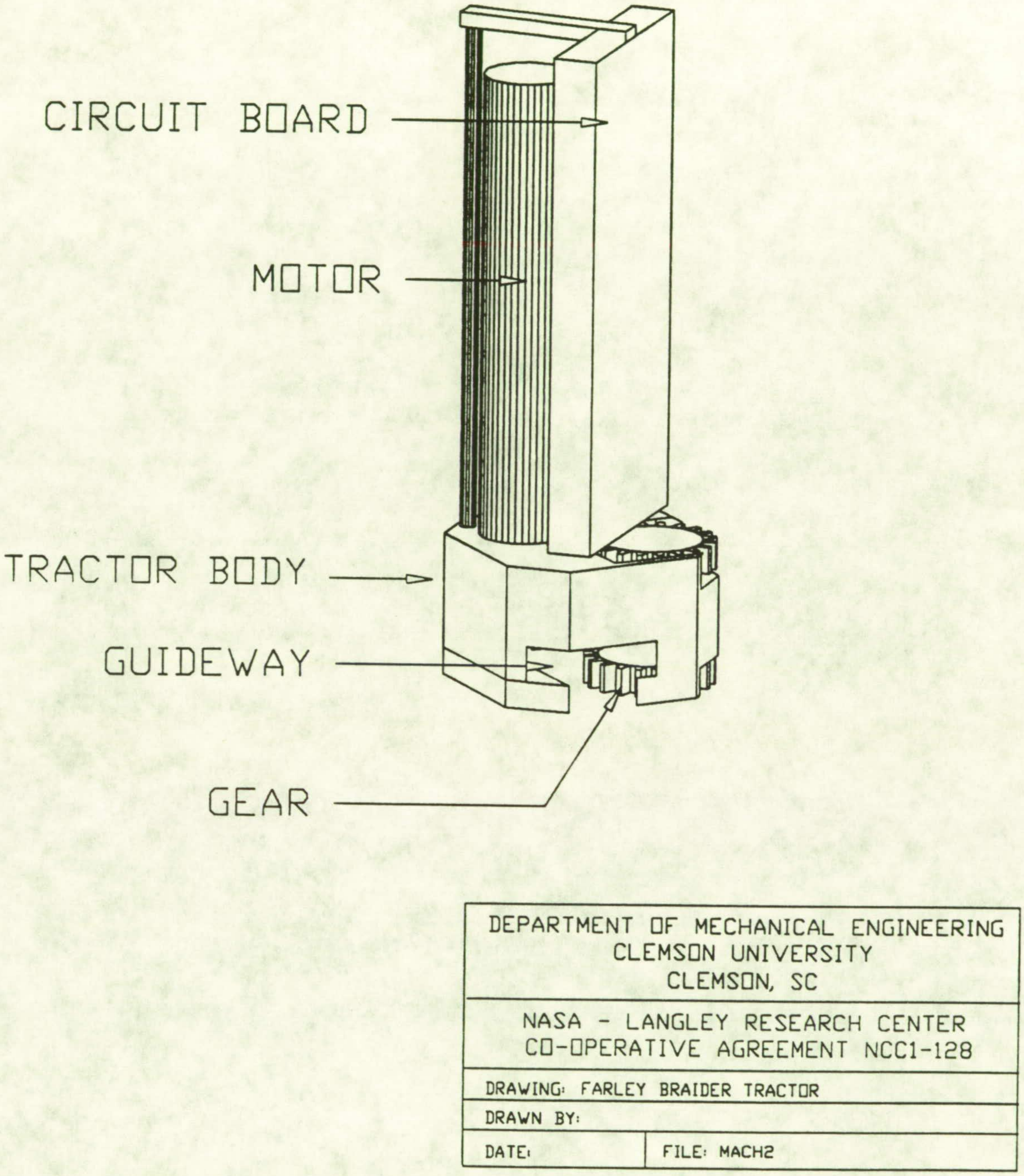


Figure B.4: The Yarn Carrying Tractor

electrical wiring in the braiding yarns or twisting the wiring as the tractors move and turn.

The turntable units which form the braiding surface (see Figure B.5.) are each a rotatable disk, pivoted on its axis so that it may assume alignment in two orthogonal directions. Mounted on the surface of each turntable is a segment of a rack, which matches the drive gear of the tractor. This rack is further mounted to a track segment, which serves to engage and guide the tractor as it moves. This surface plate is electrically conductive, and is the active conductor which transmits power to the tractor. A separate conductor in each turntable provides a return path for the electrical current. Also mounted in the turntable base are an optical emitter and detector. These are used for the transmission of control signals to and from the tractor. The turntables are rotated from the X-axis to the Y-axis, and vice-verse, by means of a spring-loaded push rod and pin assembly. This assembly is so situated that full extension of the rod will push the turntable sufficient to achieve orientation in the X axis. If the rod is fully extended in the opposite direction, it causes the turntable to rotate to the Y axis. Adjustable stops are provided to enable the adjustment of each individual turntable to ensure proper alignment. This entire push rod assembly activates an entire row of turntables as a unit. The motion of the push rod is derived from a double-acting pneumatic cylinder, which is controlled by a solenoid-actuated, pilot-

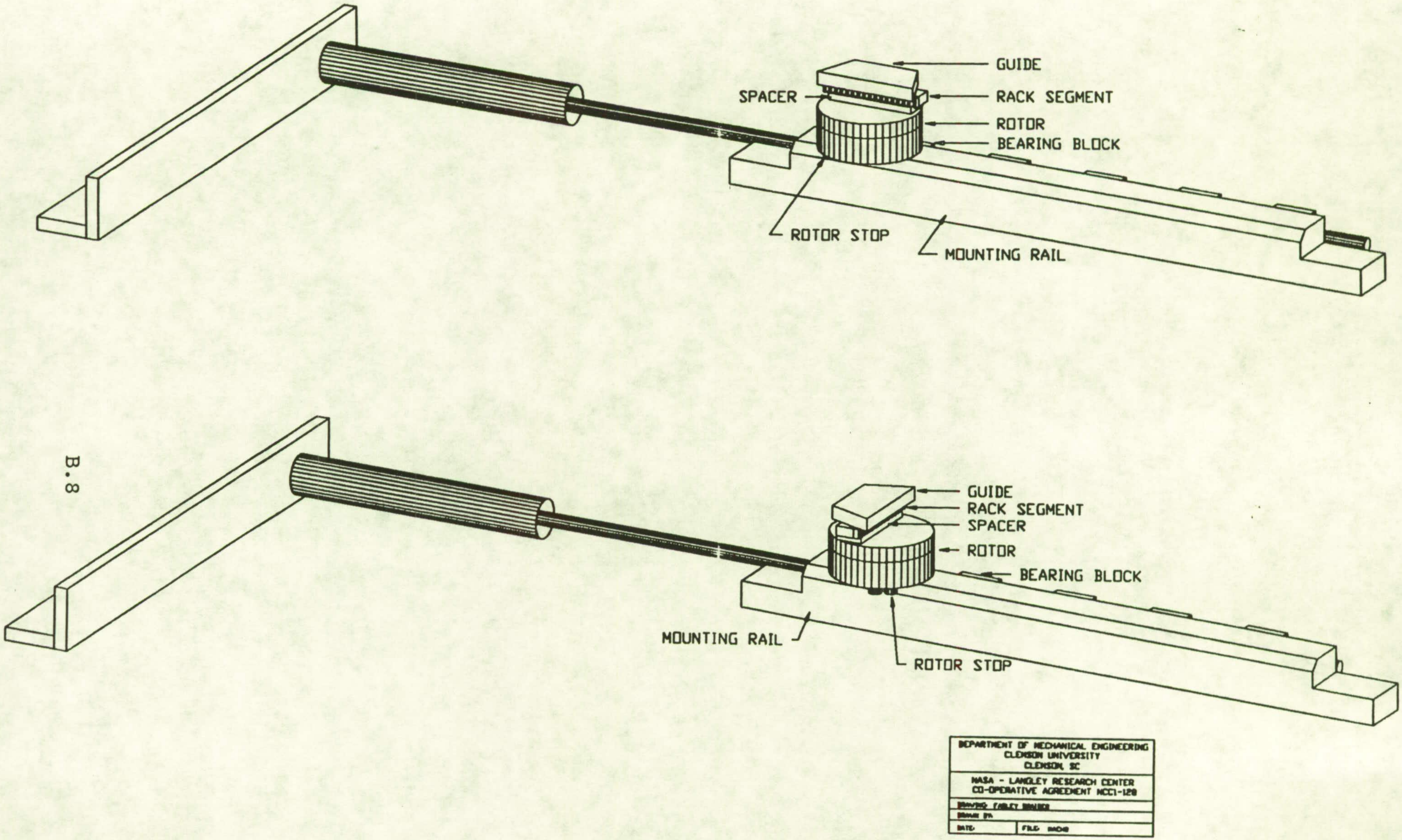


Figure B.5: The Turntable Assemblies

operated spool valve. As currently implemented, a single control valve controls not just one row of turntables, but the entire assembly. Thus, upon receipt of the control signal from the computer to rotate turntables, all turntables mounted on the surface rotate simultaneously. This then realigns all the parallel tracks in the opposite axis, making it possible for the tractors to move in that axis.

Operating Sequence:

To better understand the operation of the braider, it would be instructive to go through a sequence of operations. As an assumption of starting conditions, the braiding machine has a sufficient number of tractors loaded onto the surface, any stationary yarns have been threaded into place, the computer has been energized and the control program loaded, and all of the rotatable turntables have been oriented in the X-direction. Further, all necessary power and air is turned on and available to the braider. In this condition, all tractors are at rest. Although not absolutely necessary, in the feedback mode of operation, there is a "stop" signal present at each turntable above which a tractor is parked. Further, let it be assumed that before the braiding yarns were threaded, the tractors had all been prepositioned to their required starting positions.

At this point the computer program is started, and the run commences. The computer program, through its logic, determines

that certain of the tractors are to move in the + X direction, others in the - X direction, and the reminder are to stay stationary. Connection to the IBM pc-type computer is made via a general purpose 24-bit parallel digital interface board. The outputs of the board control the various functions of the braider interface electronics.

The control philosophy centers on the need for non-contact communication between a computer control system and several tractors. The method used for communication in the wireless link is infrared optics. This system was used because it could be implemented quickly from standard parts, and to gain experience in applying the technology to the application at hand.

Infrared emitters and detectors are located at each turntable in the braiding surface and on each yarn-carrying tractor. The emitter on any given turntable aligns with the detector on the tractor and vice-versa, provided the tractor is within an acceptable position relative to the turntable.

Information needed to control the tractors involves two pieces of data: direction of motion, and destination. This information is passed to specific locations on the braiding surface and thereby directed to the appropriate tractor, via its controller, in the form of three frequencies which modulate the infrared emitters at the present locations of the tractors. One frequency is used to start the motor in a clockwise rotation, a second frequency would be used to start rotation in the

counterclockwise direction, and the third would be used to stop motor rotation. The stop frequency is sent to the emitters at the destinations of the tractors which have started in one direction or the other. Feedback can be implemented with this system, but would permit communications only when the tractors are located at the turntables. Currently the detection of the stop frequency by the tractor detector is mirrored, via its onboard emitter to the stationary detector at each turntable. This information is relayed to the digital interface board, and polled by the computer to confirm that any given tractor has reached its ordered destination. Other information, such as yarn tension, presence of faults, and the like, could also be sent by this method.

In the present implementation, the infrared emitters located on the turntables may be addressed one at a time and modulated with any of the three frequencies mentioned above. Likewise, feedback may be received at any one address by setting the stop frequency at the tractor destination and observing the state of the feedback bit via the parallel digital interface board. Since only one location can be in communication with the computer at any given instant, in order to control more than one tractor, time-multiplexing is used to transmit and receive data, and thus achieve a psuedo-simultaneous movement of all the tractors at once. It is only necessary to start the tractors in the proper direction, one at a time, and them stop them all by sending the stop frequency to all affected destinations for

several milliseconds at a time. This process is repeated until it has been determined via the feedback system that all yarn carriers are at the desired locations. If feedback is not used, then sufficient time must be allotted to the moves ordered to ensure all tractors have had sufficient time to arrive as ordered.

The tractor onboard control circuit consists of a frequency discriminator (tone detector) and motor drive electronics. The motor is simply turned on, with the appropriate polarity voltage, or off. Since there is a significant gear reduction in the motor gearhead, and dynamic braking is incorporated into the drive electronics, there is negligible travel of the tractor beyond the point at which a stop frequency is detected, and the tractor experiences an acceptably small level of overshoot, certainly within the limits defined by the need to turn the turntables and within the signal window of the emitter/detector pairs.

Power is supplied to the tractor motors via sliding contact and isolated lands on each of the turntables. Use of the parallel digital interface is outlined in a chart given in Appendix E. On this same chart may be found the construction of the digital encoding (bytes) used. The computer uses "AND masking" to construct the various output bit patterns.

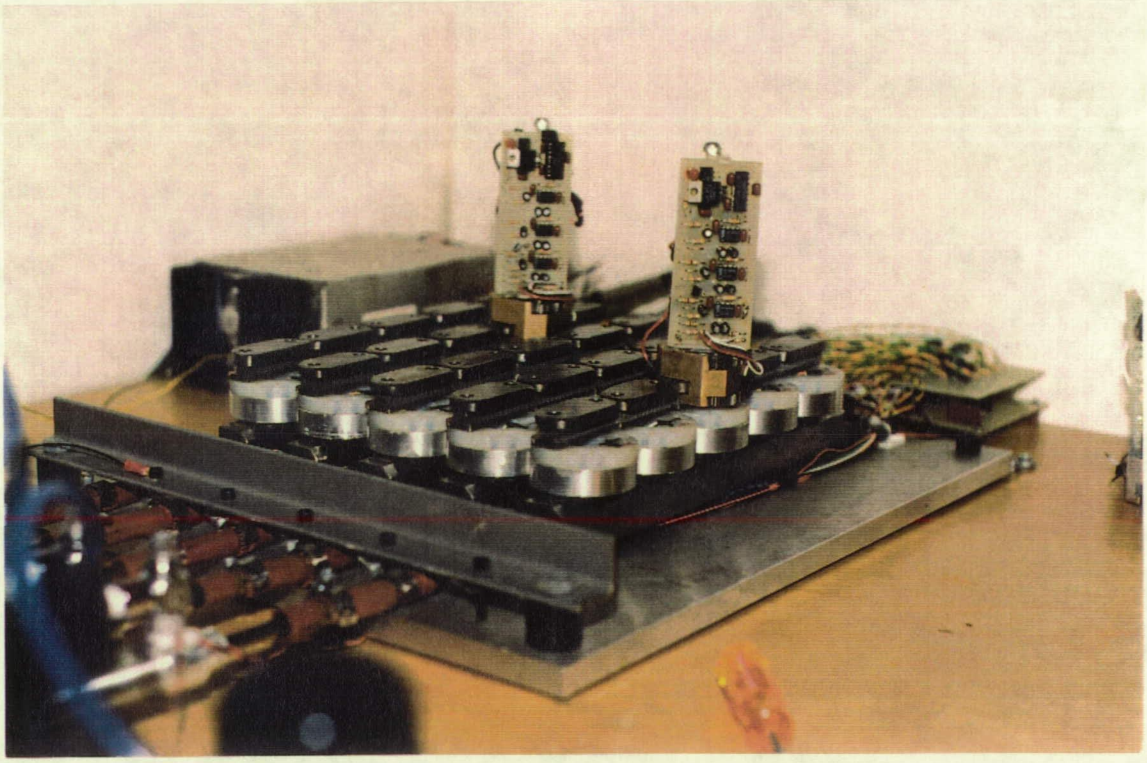
The interface electronics consist of an addressable emitter matrix which has one of three frequencies gated to the addressed infrared emitter. The frequency is chosen by the two most significant bits of the digital interface's port B. The row

address is the next three significant bits, and the column address for starting and stopping is then the three least significant bits. Feedback column address is on port C along with a single bit for table rotation. Rows of detectors are observed in parallel while the columns are scanned to detect feedback from the matrix of detectors located on the turntables. Port A is used for feedback signal input.

As described above, the tractors can all be directed to move and stop, or to remain stationary, each moving a prescribed distance in the X-direction (+ or -). Once this move is made, the computer program orders all turntables to rotate to the Y-axis. This is accomplished by control relay gating a 24 V(dc) signal to a solenoid. This activation then opens and closes ports, via pilot activated valve, to admit air to one side of a pneumatic cylinder, while venting the opposite side. Since the cylinders for all rows of turntables are ganged together, they all move simultaneously to the 90^0 rotated position and remain there until commanded otherwise.

Now that the turntables have been aligned in the Y-axis, the tractors can be commanded to move, in the same manner as before, except of course they will be moving in the Y-direction. After the Y move is completed, the turntables are rotated back to the X-axis, and another X-axis move is made. This alternating of X move, rotate, Y move, rotate is continued until such time as the entire braid is formed. (See Figure B.6). Of course, since each

X (or Y) move may be different from the preceding one, generalized motion is achieved.



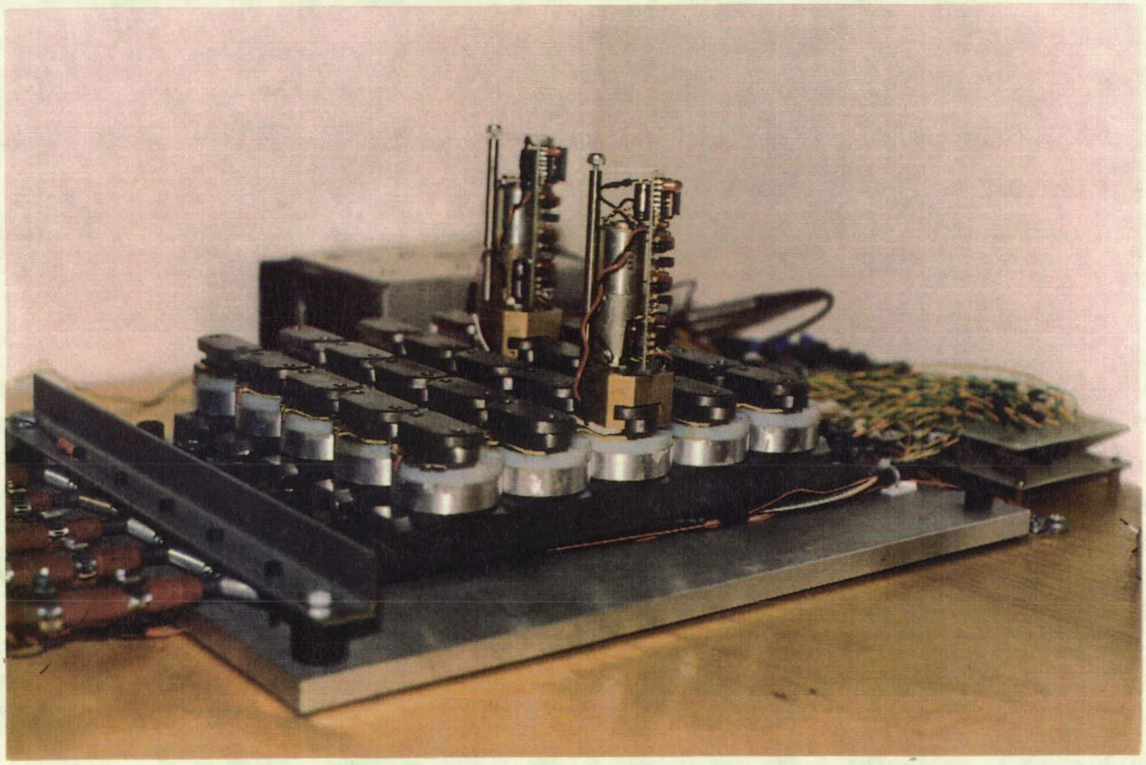


Figure B.6: Rotation of the Turntables

Appendix C:

The Shuttle Plate Braider
(Detailed Description)

The shuttle plate braider is shown in Figures C.1 and C.2, as well as in detailed drawings and photographs in this and other appendices.

The shuttle plate braider is capable of moving any yarn end from a stating point to an endpoint along an orthogonal grid of pathways, much like the motion of a cursor on a computer monitor. Since multiple yarn ends may be moved, independent of each other, and in addition, stationary, axial yarns can also be used, the shuttle plate braider is capable of making a generalized, three-dimensional braid.

The shuttle plate braider is composed essentially of the yarn carrying shuttles, the shuttle plate, and the segmented braiding surface, all with their needed controls and motive power, plus the IBM type pc computer. Each shuttle (Figures C.3 and C.4) is composed of the body, a solenoid operated engagement pin (plunger), onboard control electronics, and the yarn bobbin. The shuttle plate (Figure C.5) is a flat plate with appropriate holes and slots machined through its face so that the pins of the shuttles may pass through the holes, engaging the plate. The shuttle plate is attached to its drive mechanism so that motion may be imparted to the plate in a horizontal plane. The segmented

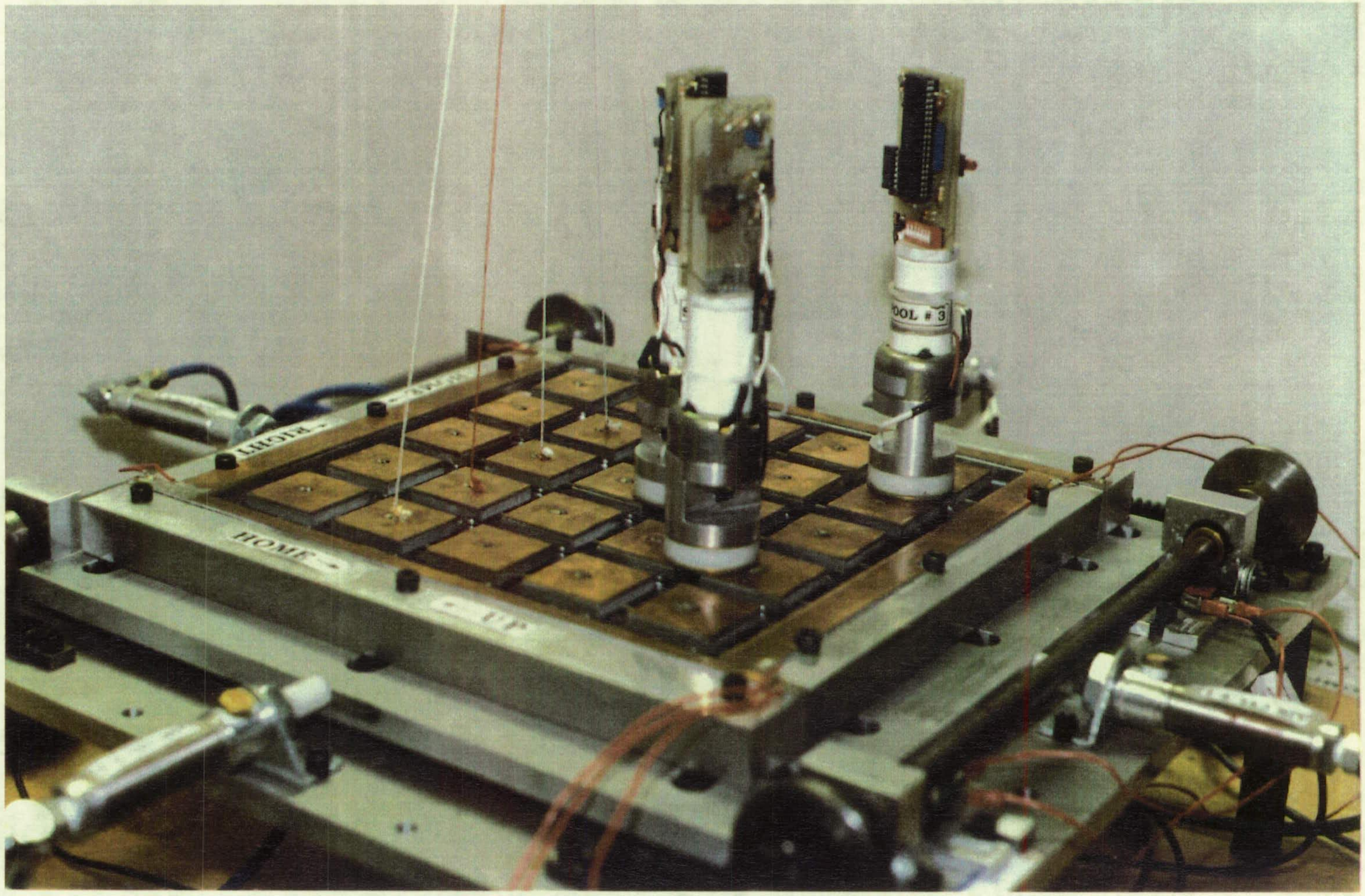
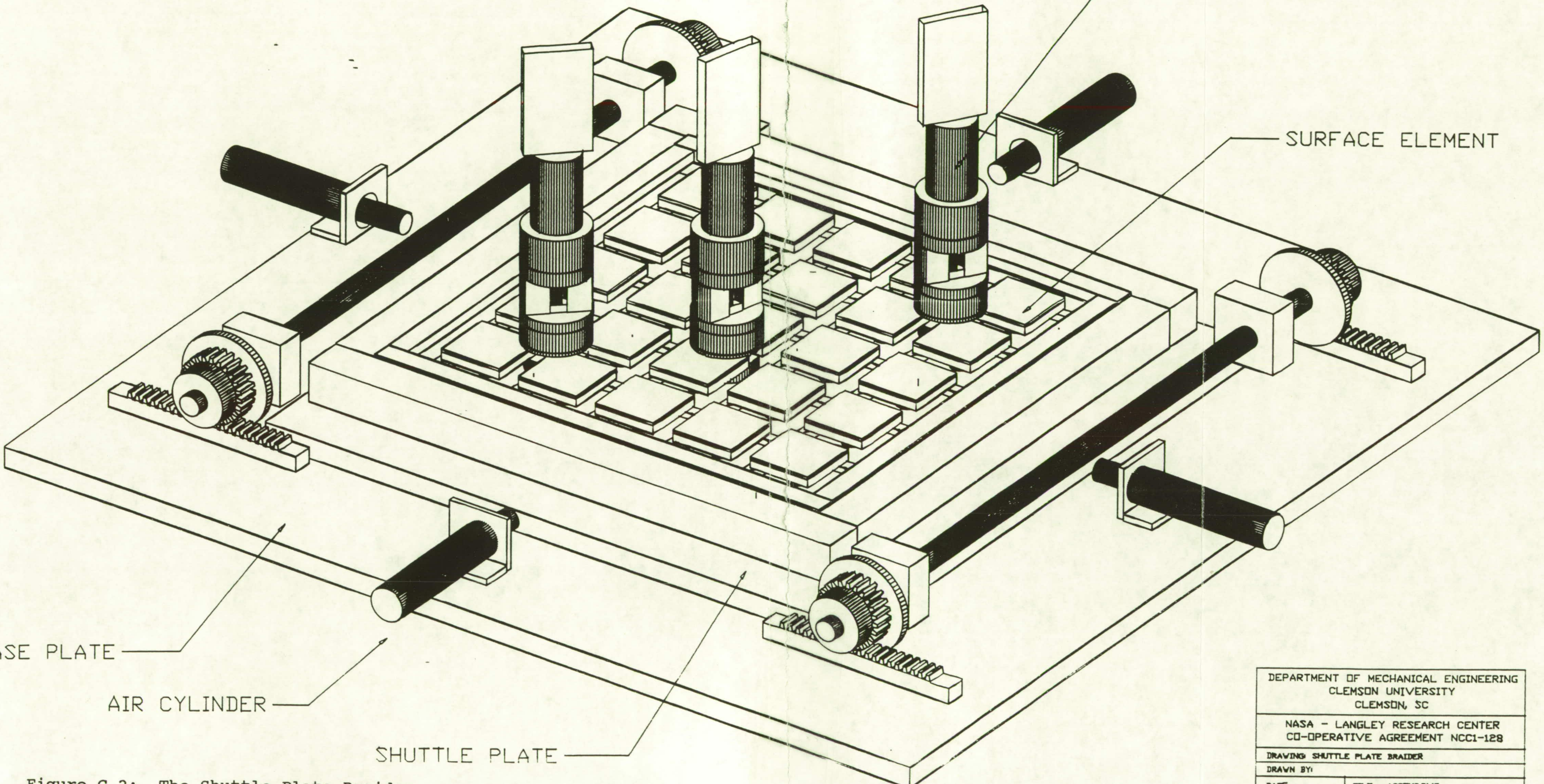


Figure C.1: Photograph of the Shuttle Plate Braider

FOLDOUT FRAME 1.

FOLDOUT FRAME 2.



DEPARTMENT OF MECHANICAL ENGINEERING CLEMSON UNIVERSITY CLEMSON, SC
NASA - LANGLEY RESEARCH CENTER CO-OPERATIVE AGREEMENT NCC1-128
DRAWING: SHUTTLE PLATE BRAIDER
DRAWN BY:
DATE: FILE: ASSEMB.DWG

Figure C.2: The Shuttle Plate Braider

braiding surface (Figures C.6 and C.7) forms the travel grid on which the shuttles travel. It also serves as the electrical conductors needed to send power and communication signals to the shuttles.

When assembled the braider consists of a segmented surface below which lies the shuttle plate. The shuttles are supported and guided by the segmented surface and are caused to move by engagement with the shuttle plate. The desired movements of the shuttles is obtained by commanding them to individually engage the shuttle plate as appropriate. By properly engaging and disengaging the plate, the shuttles move in a series of steps along orthogonal motion axes.

Operating Sequence:

To better understand the operation of the shuttle plate braider, a sequence of operations will be described. It is assumed as a starting condition that all requisite power (air and electrical) is available, that the computer is energized and loaded with the control program, and that the required number of shuttles have been loaded onto the braider. It is further assumed that all shuttles are in their starting positions, and all yarns, both moving and stationary, have been threaded.

As the program executes, the first physical action required is for the set of shuttles which are to travel in this first move to engage the shuttle plate. A d.c. power supply, of nominal 20

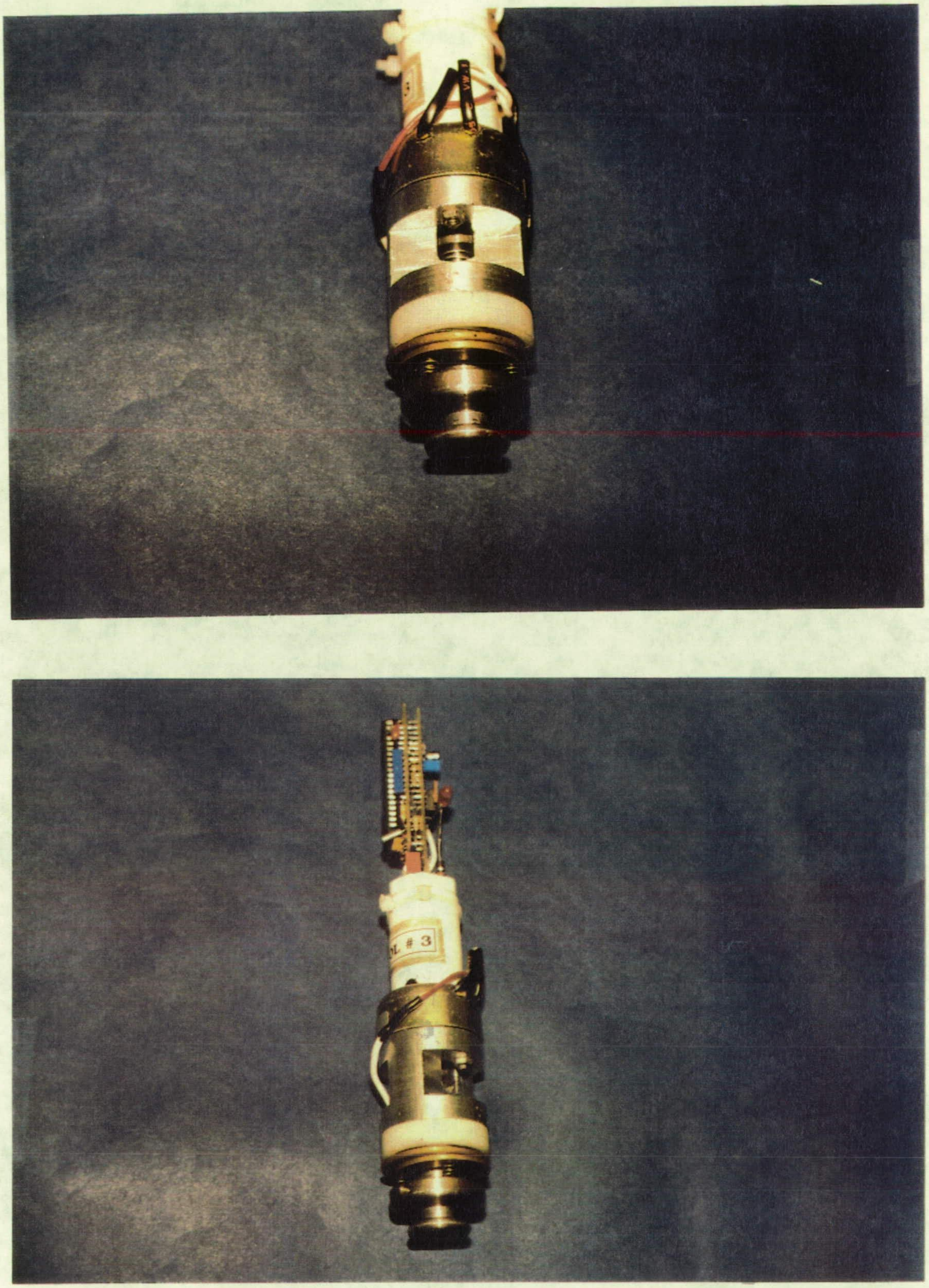
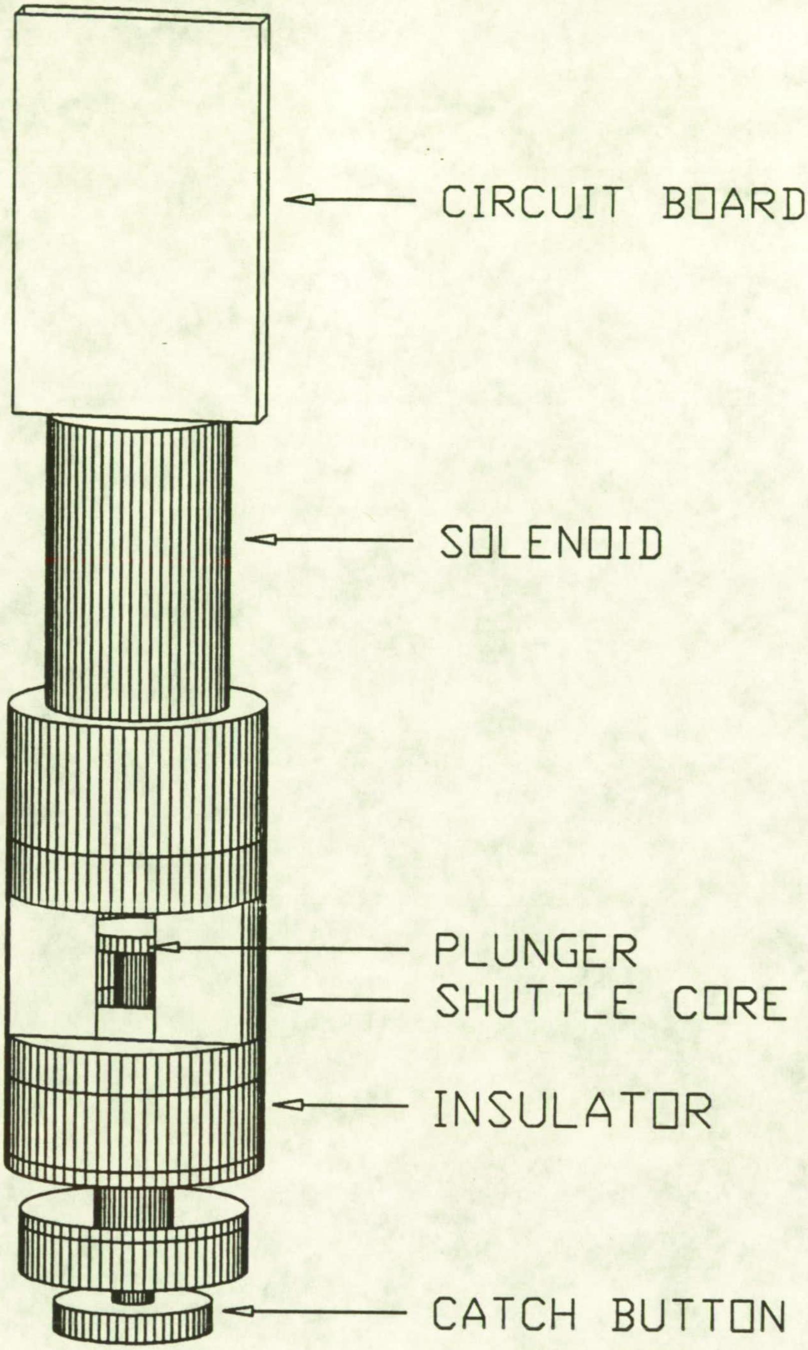


Figure C.3: The Shuttle



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NASA - LANGLEY RESEARCH CENTER CO-OPERATIVE AGREEMENT NCC1-128	
DRAWING: SHUTTLE PLATE BRAIDER SHUTTLE	
DRAWN BY:	
DATE:	FILE: PLATE.DWG

Figure C.4: The Shuttle

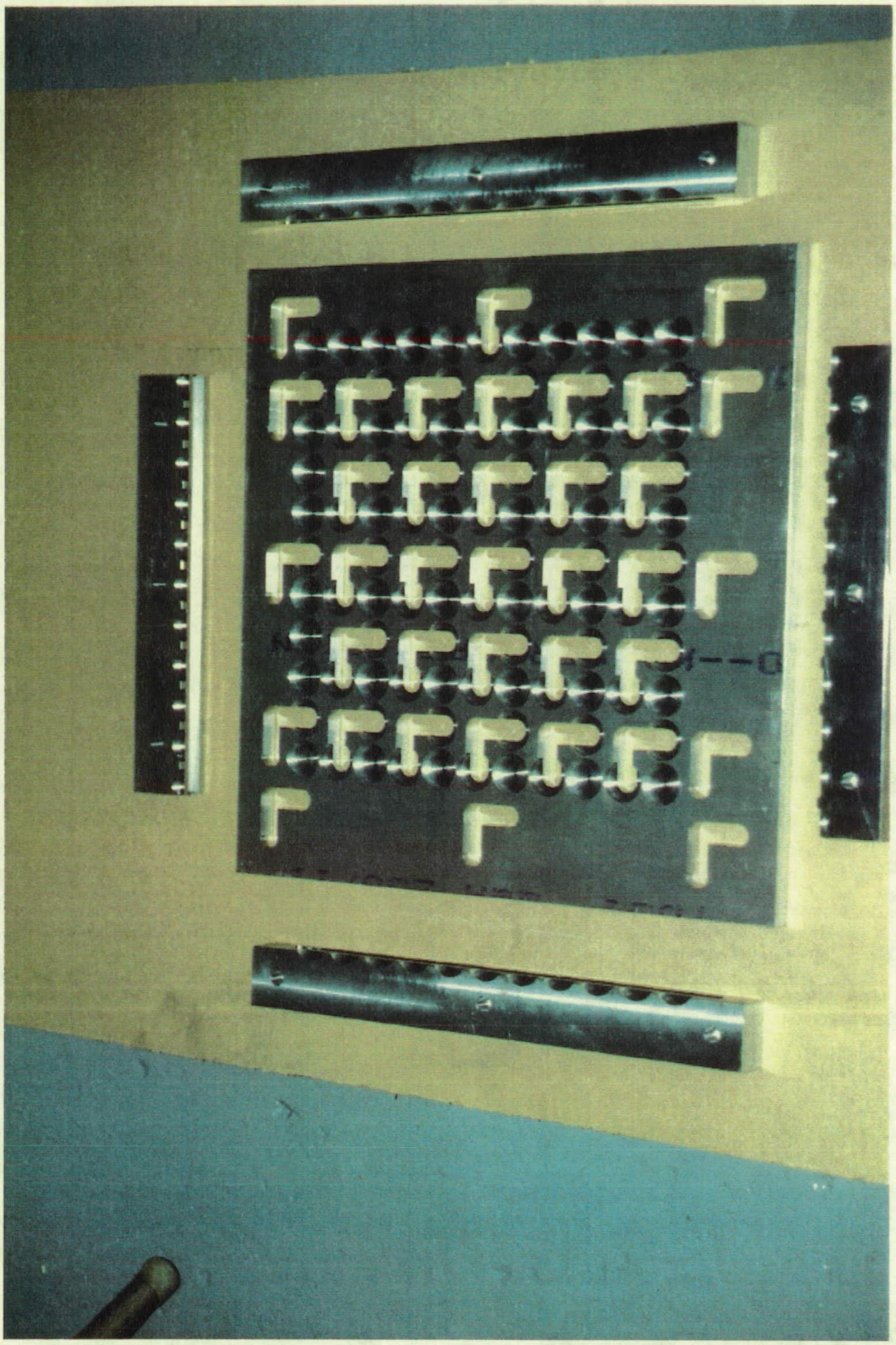
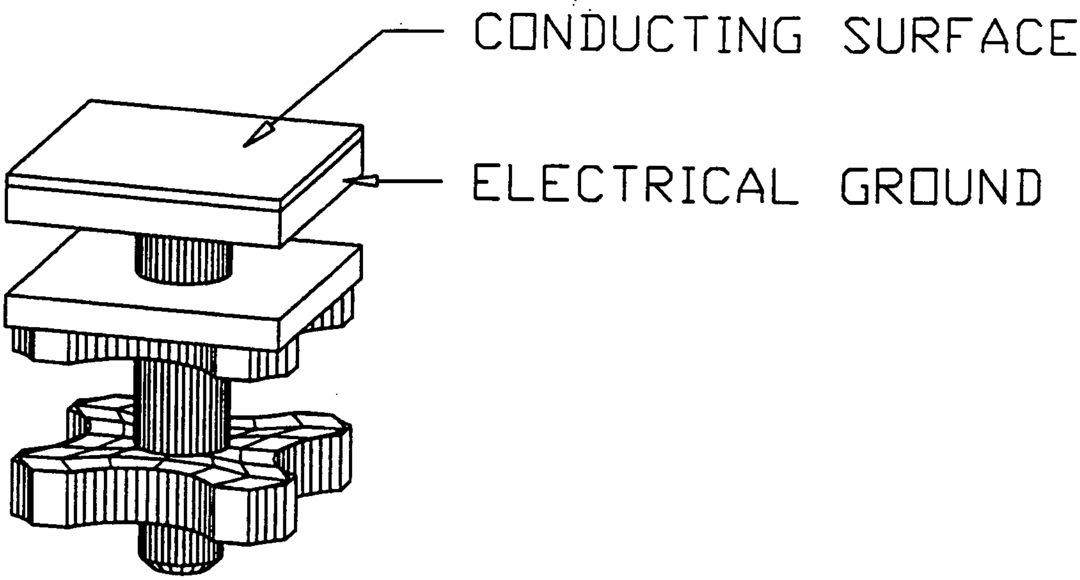


Figure C.5: The Shuttle Plate



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NASA - LANGLEY RESEARCH CENTER CO-OPERATIVE AGREEMENT NCC1-128	
DRAWING: SHUTTLE PLATE BRAIDER - SURFACE ELEMENT ASSEMBLY	
DRAWN BY:	
DATE:	FILE: PLATE.DWG

Figure C.6: The Segmented Surface Element

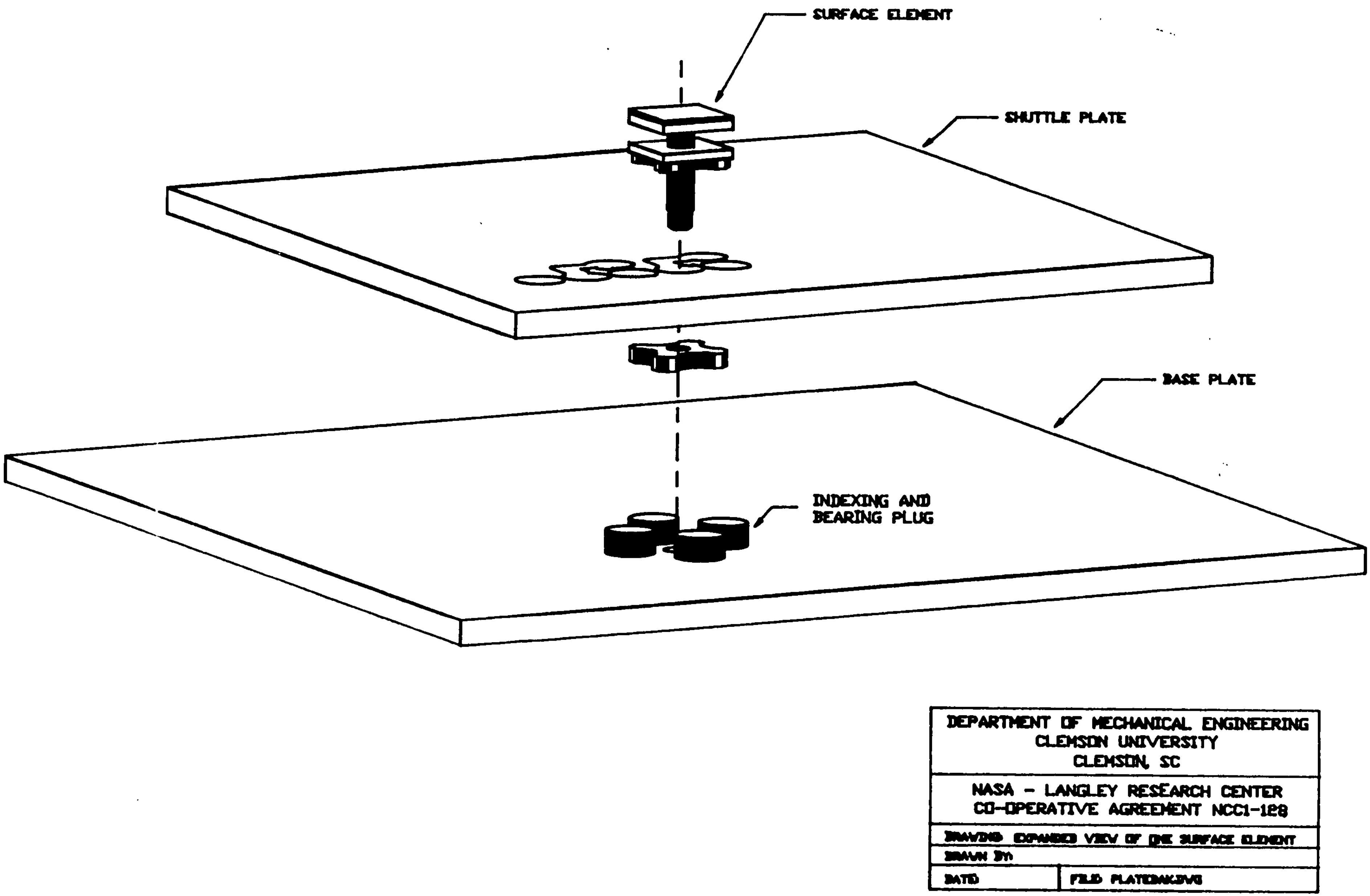


Figure C.7: Assembly of a Single Surface Element

volts, applies voltage to the segmented sections of the braiding surface. The upper surface is conductive and electrically isolated from the underside, and thus two sides of the circuit are provided to the shuttles. When it is desired to communicate with the shuttles, the power supply is temporarily "decoupled" from the surface by insertion of resistance (by means of opening parallel relays) in series with the output of a low impedance power supply. If the impedance of an additional active device in the output circuit is of the same order of magnitude as this output decoupling resistor, then a voltage excursion down to approximately 8 volts is achieved. This excursion is readjusted, by appropriate circuits, to the CMOS logic levels of 0 to 12 volts. By appropriate pulsing of this voltage excursion, a series of ones and zeroes can be transmitted across the segmented plate. The host computer is used to generate this data bit string. Onboard each shuttle is a Motorola 14469B Asynchronous Serial Receiver/Transmitter which is address-programmable, and is shown in Figure C.8. A unique address is programmed onto each shuttle. If an individual shuttle detects its address being transmitted across the grid (segmented surface), its circuit generates a "valid address pulse." If not, no such pulse is generated. With the presence of a valid address pulse, and if the device is configured to receive command data, the device will accept a command, in this case to either turn the shuttle solenoid On or Off. It should be noted that this same asynchronous

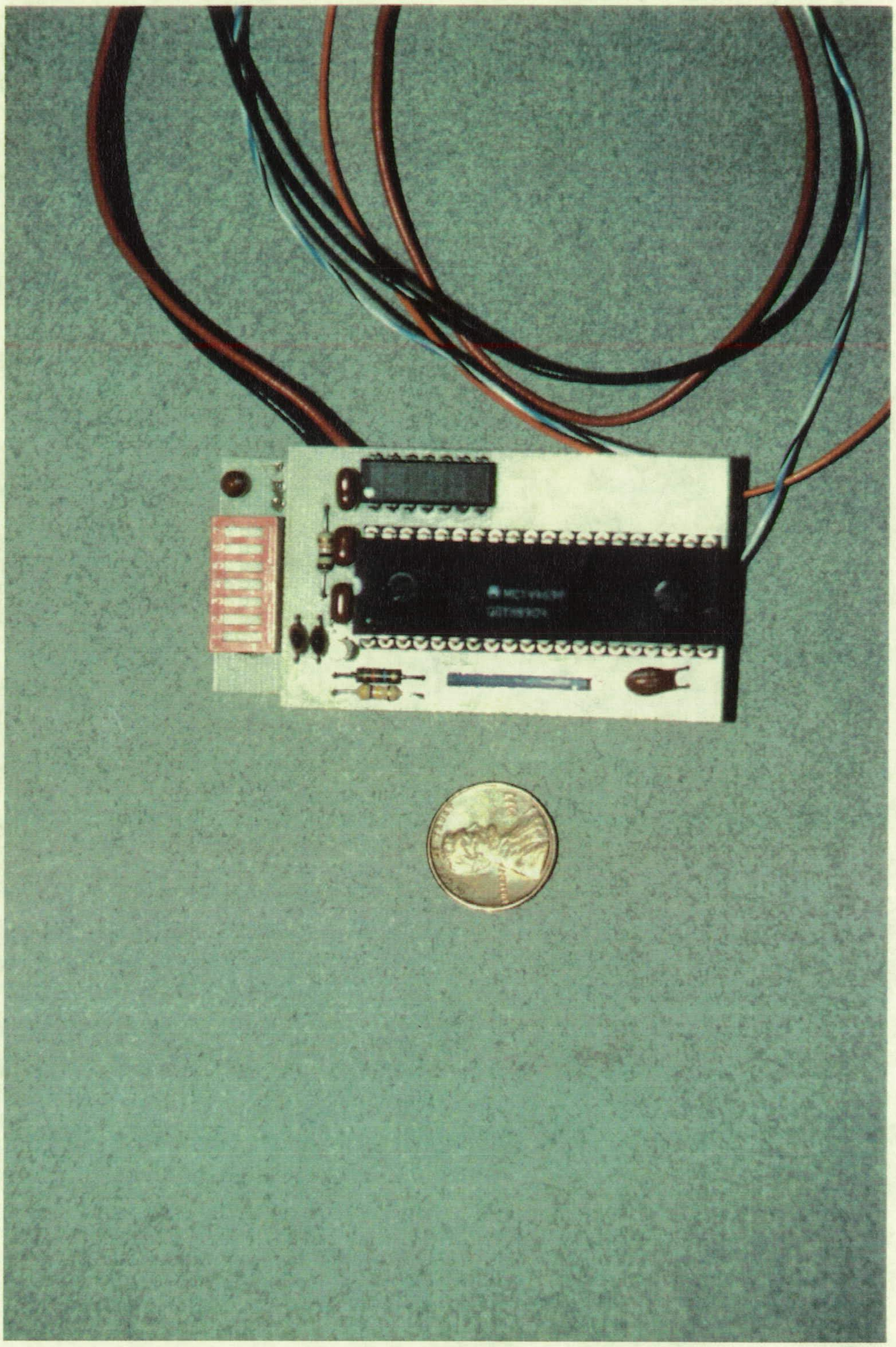


Figure C.8: The Shuttle Circuit Board

transmitter/receiver may be used to transmit feedback and other data to the computer in the future. The present system is not configured for this capability. Since the Motorola circuit is capable of 128 different addresses (seven binary bits), that number of independent shuttles can be addressed and commanded to turn on or off by this scheme with no further development. Nearly unlimited expansion is possible by a number of methods.

Upon receipt of the appropriate signal, an individual shuttle responds by setting a flip-flop amplifier to the appropriate condition. At this point data communication has been completed, and the power supply is recoupled, restoring full voltage to the segmented surface. This causes actuation of those solenoids which had been commanded to operate, with all others remaining deactivated. Thus certain of the shuttles engage the shuttle plate by extending their pins into mating holes in the shuttle plate, while the others remain at rest. (See Figures C.9 and C.10.)

At this point, the shuttle plate is caused to move in a specified direction, for example, in the +X axis. The movement of the shuttle plate is caused by pneumatic cylinders controlled by a solenoid actuated, pilot-operated, pneumatic valve. The shuttle plate thus moves in the +X direction, but by a distance of a/2, where a is the braiding surface pitch, the distance between two adjacent tracks on which shuttles can move. At this point, by decoupling the power supply and again signaling the shuttles, they

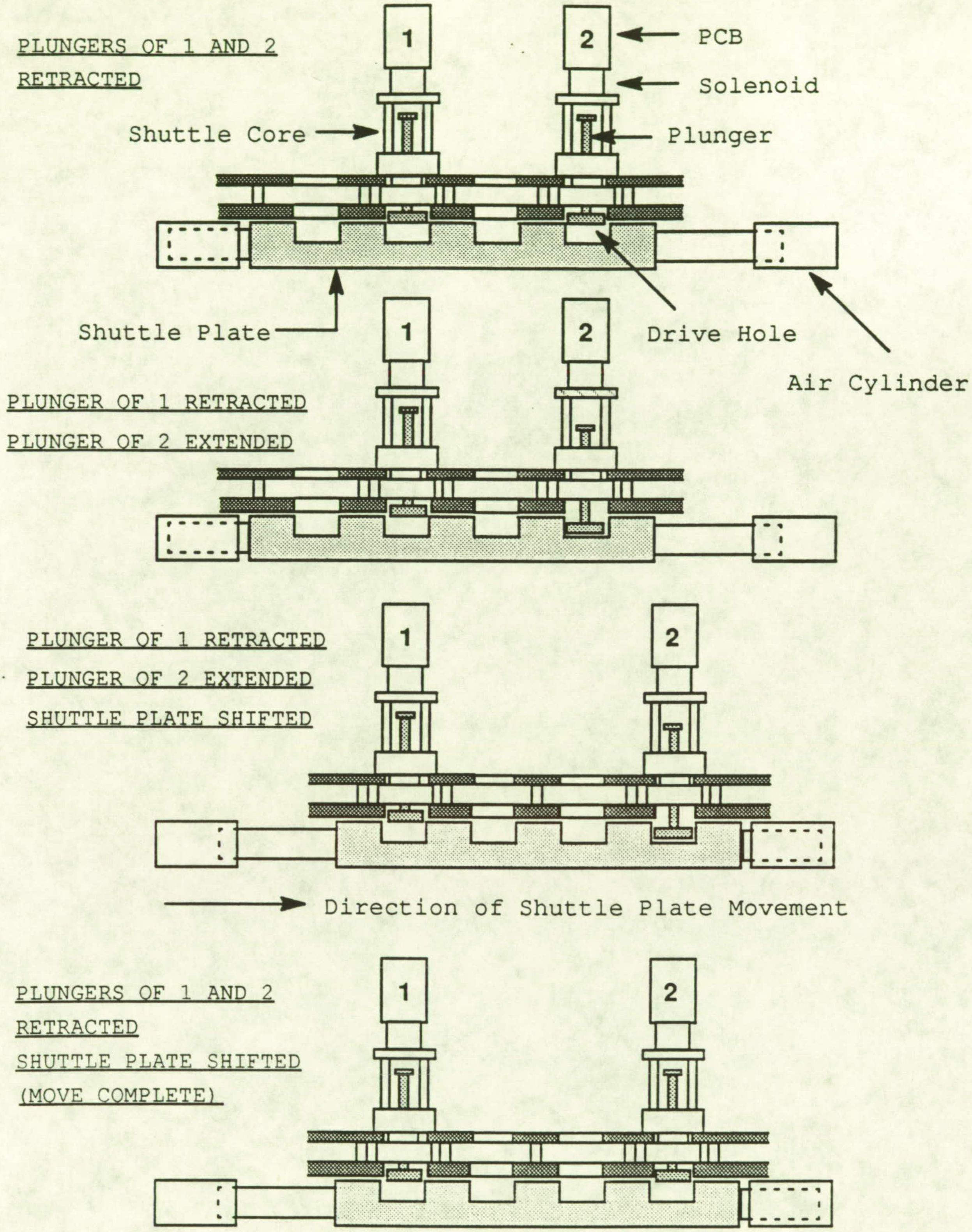


Figure C.9: The Shuttle in Various Conditions of Engagement

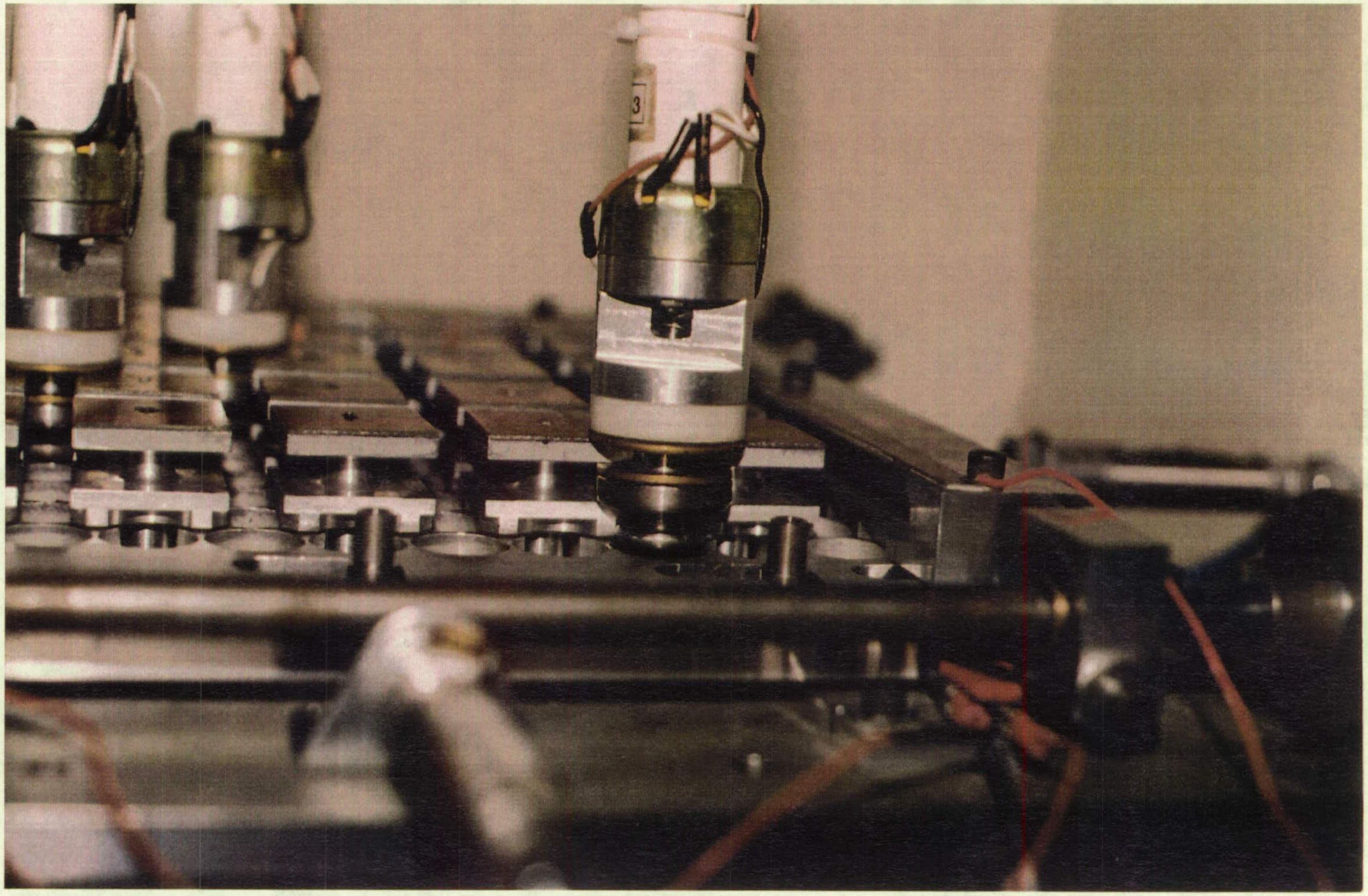


Figure C.10: Photograph of the Engaged Shuttle

are made to release the shuttle plate. The command sequence is then repeated and the shuttles waiting to move in the -X direction engage the shuttle plate. The shuttle plate then moves back to its original (home) position, carrying those shuttles which need to move in that direction. This sequence of engage shuttle, move shuttle plate, disengage shuttle, engage shuttle, move shuttle plate, is then repeated, but along the Y axis. The entire sequence is then repeated, and so, by the series of half steps, all of the shuttles will eventually be moved from point to point until such time as all moves have been made to generate the desired generalized braided structures.

Appendix D: Computer Programs

This appendix provides the computer programs that are used to operate the two generalized 3-D braiders as they are currently configured and discussed in this report.

For each braider, a brief description of how to operate the braider is given, including a list of some key program variables. The coding of the two programs follow the description of both braiders. The programming language is BASIC. This language was chosen because it is easy to use and thus fit the objective of allowing quick implementation and experimentation with various schemes of control. There are, obviously, faster languages and refined coding schemes which would be used in improved designs.

Abbreviated Instructions for the Modified Farley Braider

Please refer to the flow chart, Figure D.1, to aid in understanding these instructions. Assuming all connections have been made to the braider, electrical supply to the machine should be set at about 19.5 Vdc and the air supply should be set at between 45 and 50 psig. The host computer should be loaded with the operating program and the "moves" data file installed in memory, if the "auto" mode will be run. See Figure D.2 for information on the format of this data file.

The F2 key on the keyboard is used to start the program. A message "PRESS F1 TO PAUSE ANYTIME" will appear. By pressing F1 the user can temporarily delay the program at any point in its run. At this point program initialization, as well as braiding surface orientation instructions will be given on the computer screen, walking the user through the initialization procedure. After the program and braider are initialized, the program inquires about the presence and location of the yarn-carrying tractors. This is followed by instructions on loading the tractors onto the braiding surface and moving them to their start positions. Once this is completed, the system is ready to run.

At this point, manual or auto mode is selected, as well as the number of cycles to run. Further, if the operation is a restart after a partial run, a provision is made to start the data run in the middle of the data set, using the skip command. This

decision, as well as the number of moves to skip, is made at this point. These decisions having been made, the system proceeds with the braiding instructions (auto mode) as coded into the data file, or operates interactively with the user (manual mode) until the braiding instructions are completed.

The following is a definition of some key user variables from the control program which may not be self-evident.

BUGGYON: This variable specifies the starting status of the yarn-carrying tractors (buggies). A value of Y (default value) means the tractors are already loaded onto the braider. In that case the program prompts the user for initial destinations of each tractor. If the value is N, then the prompt instructs the user, interactively, on loading the tractors onto the surface.

MAN: This variable sets the program to run in either manual or automatic mode. The default value is N (auto). If auto mode is chosen, a prepared "moves" data file must be available.

CYCLENO: This is a counter, telling the operator which cycle number the program is is.

NOCYCLES: This is the number of times the user wants the program to read and run a data file , while in the auto mode. The full data file is considered one cycle. Thus repetitive cycling of the machine is possible, if desired.

MOVENO: This is a counter indicating the current move number within each cycle, when the machine is in the auto mode. This variable is important in restarting after an interruption, since it allows the operator to know the number of moves to skip on restart.

SKIP: This command variable is used to inform the program that steps are to be skipped in the first cycle (only) upon restart.

SKIPNO: This variable is set by the user to indicate the number of moves the user wishes to skip upon restart. The program skips to the move number,n, specified by the user, and hence skips n-1 moves.

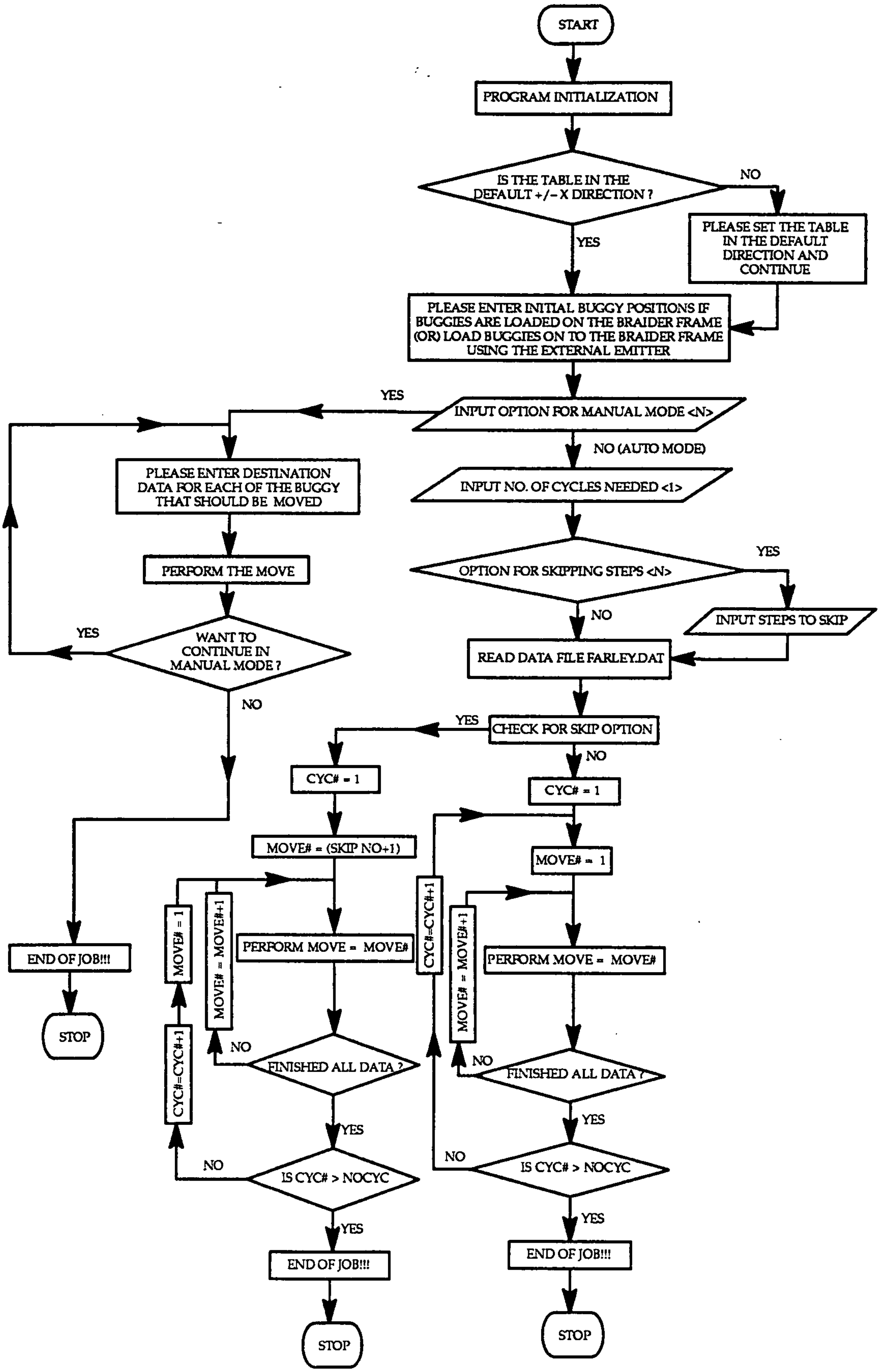


Figure D.1: Flow Chart, Modified Farley Braider

To run the modified Farley braider in auto mode, a data file of moves is required. This is established as a BASIC data file, in the currently active subdirectory, and is referred to by the main program as "FARLEY.DAT". As currently configured, the data is read in groups of three, since there are three yarn-carrying tractors. Each destination of each tractor is specified as a row and column. Thus the location of first row, second column, is specified as 12. The layout of the rows and columns, as currently implemented, is given pictorially below.

To specify a set of moves then, the programmer would specify the desired destinations of the three tractors moving in the X-direction, followed by the Y-destinations, and so forth. Stationary "moves" are specified by restating the current location of that particular tractor. The first specified destination in each triple is for tractor #1, the second for tractor #2, and the third for tractor #3.

Thus let us assume that the tractors are presently located as follows:

Tractor #1 -- location 13
Tractor #2 -- location 32
Tractor #3 -- location 52

For an automated set of moves, we would specify the X-direction destinations, #1 to 14, #2 to 31, and #3 to 55, which is a one space move right(+X) by #1, a one space move left(-X) by #2, and a 3 space move right (+X) by #3. This X-direction move would be specified as 14,31,55.

Next the Y-direction moves, for example, #1 to 44, #2 to 41, and #3 to 25. This set is then 44,41,25.

Now again, the next set of X-direction moves, for example, 43,41,22. (Note the non-move by tractor #2.) This then continues onward alternating X, Y until all moves are specified.

The entire data file for the above specified moves would read as:

14,31,55,44,41,25,43,41,22

```
        51 ---- 52 ---- 53 ---- 54 ---- 55
        |       |       |       |       |
        41 ---- 42 ---- 43 ---- 44 ---- 45
   ^    |       |       |       |       |
   |    31 ---- 32 ---- 33 ---- 34 ---- 35
  +Y    |       |       |       |       |
        21 ---- 22 ---- 23 ---- 24 ---- 25
        |       |       |       |       |
        11 ---- 12 ---- 13 ---- 14 ---- 15
          +X ->
                ARRAY PATTERN
```

Figure D.2: Data File for Modified Farley Braider

Abbreviated Instructions for the Shuttle Plate Braider

Refer to Figure D.3 for the flow chart, which would be useful in following this discussion. It is assumed that all needed connections have been made between braider and computer, that the electrical power supply is connected and control air is provided. The air pressure should be 45 psig. The voltage at the braiding surface should be between 8.00 and 8.04 Vdc. (If it is not, adjust the power supply voltage to the correct voltage and then press the reset on the Computer Interface and Voltage Level Control box.) Load the BASIC language control program "BRAID.BAS." Be sure that a "moves" data file is provided. See Figure D.4 for information on this data file.

By pressing the F2 key, the user begins operation of the program. The running of the program may be interrupted at any time by pressing F1. The program then initializes internal variables, and determines the initial status of the braider by obtaining data from the user in an interactive mode. Once this is accomplished, the user selects operation in either auto(matic) or manual mode. It is also possible at this point to select a multiple run through the data file and thus to accomplish repetitive cycling of the braid pattern. Further, should this operation be a restart of an aborted run of the machine, there is a provision at this point to instruct the program to skip the first specified moves in the data file. The selection to do so

would occur at this point. Also, the choice of whether to autosequence is made. Autosequencing is normally used, but may be turned off to allow manual stepping through a set of moves contained in the data file. Once these decisions have been made, the program and braider will commence operation (in the auto mode) or, by interacting with the operator, obtain data and make individual moves (in manual mode) until such time as the braiding sequence is completed.

Some key user program variables are as follows:

POSI: This is the user input value of the current position of the shuttle plate, specified at start-up. The values of the variable are 1 for the UP position and 2 for the RIGHT position. All other values are interpreted as the default value, which is HOME. (Home is Down and Left.)

POSN: This is a program generated value reporting the current position of the shuttle plate while the program is running. This variable can take on any one of the three values: UP, HOME, or RIGHT.

DIRN: This variable gives the direction of the move the shuttle(s) is to take. The user inputs this value directly through the console in manual mode or through the data file in auto mode. The variable takes on values of U, D, R, or L (up, down, right, or left).

MAN: This variable has the values Y or N and allows the user to select between manual and automatic mode.

AUTOSEQ: Thus variable takes on the values Y or N with default as yes. It is used in both the manual and auto modes. When autosequence has been selected the shuttle moves automatically as the computer orders the move. If autosequence is turned off, the computer orders a shuttle move, but the actual physical move does not occur until the user orders the movement by pressing the ESCAPE key.

SKIP: This command variable is used when in the auto mode to allow the user the option to skip beginning moves in the data file. This option is needed for a restart after an interruption to a sequence of moves.

NSKP: This is the number of steps the user wants to skip using the skip command.

NOFCYCLES: This is the number of times the user wants the program to repeat the reading of the data file and subsequent moving of the shuttles. The entire data file is considered one cycle. The variable is used in the auto mode only, and allows periodic repetition of a braiding pattern if desired.

CYCLENO: This is a counter, showing the current cycle number.

BCNT: This is a counter showing the current move number within the current cycle, while operating in auto mode.

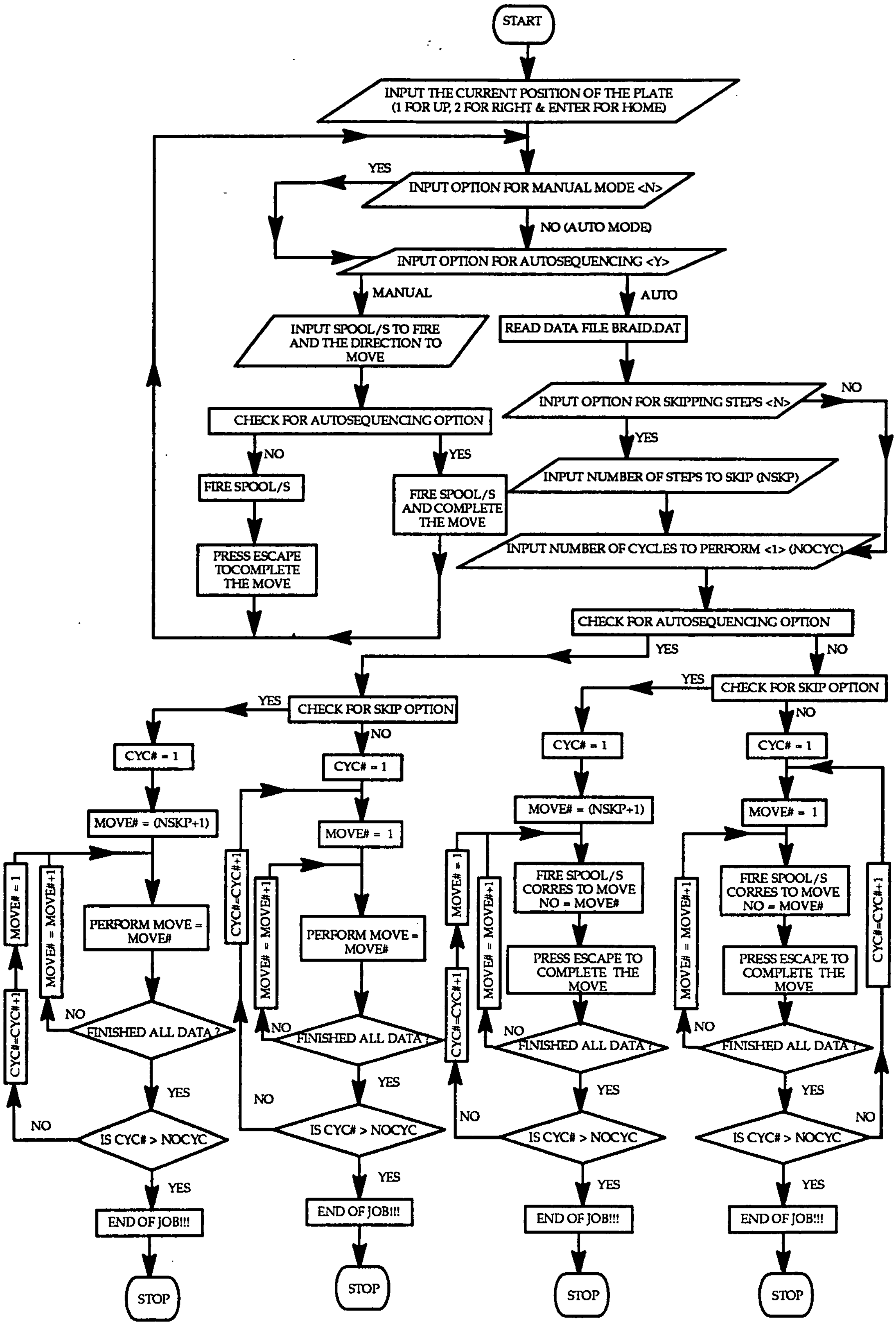


Figure D.3: Flow Chart, Shuttle Plate Braider

To run the shuttle plate braider in auto mode, a data file of moves is required. This is established as a BASIC data file, in the currently active subdirectory, and is referred to by the main program as "BRAID.DAT". As currently configured, the program expects to see three shuttles, and have one of four directions specified, with U representing an up move, D for down, R for right, and L for left. The data base expects to see the specifying number of the spool (1, 2, or 3) or spools, in any order, followed by the direction of the move.

Thus a data file which read:

1,2,U,3,D,1,2,U,3,D,2,R,3,1,L

would be interpreted as moving shuttles #1 and #2 a step up, followed by #3 moving a step down, then a repeat of those moves, followed by #2 moving a step right, then #1 and #3 moving a step left. (By inserting a zero, 0, in the sequence instead of a shuttle number, the program can be made to temporarily halt, but this is a programming aid, not normally used.)

Also, since as presently configured, the shuttle plate carries each specified shuttle one-half grid increment in each move, and wasted moves are undesirable, the programmer should exercise caution to ensure impossible moves are not specified, but that all desired moves occur as the shuttle plate goes through its normal motion of up, down, right, left. As currently implemented, the control program optimizes the motions of the shuttle plate based upon the next required shuttle move, avoiding wasted motions of the plate.

Figure D.4: Data File for Shuttle Plate Braider

SHUTTLE PLATE BRAIDER PROGRAM

```
10 CLS:KEY OFF'********** MODIFIED SPOOL CONTROL PROGRAM

20 DIM BRAIDATA$(500)'******** 01/30/91 ********

30 KEY(1) ON: ON KEY(1) GOSUB 2110

40 OPEN "COM1:2400,E,7,1,DS"AS #1:'****** BRAID.BAS ******

50 OUT &H3FB,128:OUT &H3F8,225:REM---- 512 BAUD ----

60 OUT &H3FB,27:IF INP(&H3FB)<> 27 THEN BEEP:COLOR
5:PRINT"SETUP ERROR":COLOR 7:STOP

70 COLOR 25:LOCATE 8,20:PRINT "PRESS F1 TO PAUSE ANY
TIME":COLOR 7

80 NOFSPOOLS=3 '***** Selectable No of Spools, Maximum 9'

90 NOFSPOOLS$=CHR$(48+NOFSPOOLS)

100 LOCATE 10,1:COLOR 3:INPUT"PLEASE INPUT THE CURRENT
POSITION (1 FOR UP & 2 FOR RIGHT) <HOME> ";POSI$:COLOR 7

110 IF POSI$="1" GOTO 120 ELSE IF POSI$="2" GOTO 130 ELSE
GOTO 140

120 POSN$="UP":LOCATE 24,1:PRINT SPACE$(79):LOCATE
24,35:COLOR 6:PRINT"CYCLE UP":COLOR 7:GOTO 160

130 POSN$="RIGHT":LOCATE 24,1:PRINT SPACE$(79):LOCATE
24,35:COLOR 6:PRINT "CYCLE RIGHT":COLOR 7:GOTO 160

140 CYCLE$="HOME ":GOSUB 1930:'** Check for Home **

150 POSN$="HOME"

160 MAN$="N"

170 LOCATE 11,1:COLOR 2:INPUT "DO YOU WANT TO RUN IN MANUAL
MODE <N> ";MAN$:COLOR 7

180 COLOR 14:INPUT"DO YOU WANT AUTO SEQUENCING <Y>
";AUTOSEQ$:COLOR 7

190 IF AUTOSEQ$ <> "N" AND AUTOSEQ$ <> "n" THEN AUTOSEQ$ = "Y"
```

```
200 IF MAN$ <>"Y" AND MAN$ <> "y" THEN MAN$="N"
210 IF MAN$="N" THEN 220 ELSE 320
220 OPEN "BRAID.DAT" FOR INPUT AS #3
230 INDX = 0
240 WHILE NOT EOF(3)
250 INDX=INDX+1
260 INPUT#3,BRAIDATA$(INDX)
270 IF BRAIDATA$(INDX)>="a" AND BRAIDATA$(INDX) <="z" THEN
BRAIDATA$(INDX) = CHR$(ASC(BRAIDATA$(INDX))-32)
280 WEND
290 INDX=INDX+1:BRAIDATA$(INDX) = "E"
300 CLOSE(3)
310 GOTO 430
320 NOFCYCLES=1
330 GOSUB 1540
340 LOCATE 13,7:COLOR 12:PRINT "PLEASE INPUT SEQUENCE
CHARACTER BY CHARACTER ":COLOR 7
350 INDX = 1
360 COLOR 9:INPUT "INPUT NEXT CHARACTER OF SEQUENCE
";BRAIDATA$(INDX):COLOR 7
370 IF BRAIDATA$(INDX)>="a" AND BRAIDATA$(INDX) <="z" THEN
BRAIDATA$(INDX) = CHR$(ASC(BRAIDATA$(INDX))-32)
380 IF (BRAIDATA$(INDX) >="0" AND BRAIDATA$(INDX)
<=NOFSPOOLS$) OR BRAIDATA$(INDX)="U" OR BRAIDATA$(INDX) =
"D" OR BRAIDATA$(INDX)="L" OR BRAIDATA$(INDX)="R" THEN 400
ELSE 390
390 BEEP:COLOR 13:PRINT "ERROR IN DATA, PLEASE INPUT
```

```
AGAIN":COLOR 7:GOTO 360
400 IF BRAIDATA$(INDX) < "0" OR BRAIDATA$(INDX) > NOFSPOOLS$
THEN 410 ELSE 420
410 INDX=INDX+1:BRAIDATA$(INDX)="E":GOTO 510
420 INDX=INDX+1:GOTO 360
430 '
440 BCNT=0: INDX=0
450 NSKP=0:CYCLENO=0
460 COLOR 3:INPUT "DO YOU WANT TO SKIP STEPS <N>
";SKIP$:COLOR 7
470 IF SKIP$<>"Y" AND SKIP$ <> "y" THEN 490
480 COLOR 5:INPUT "INPUT NO. OF STEPS TO SKIP ";NSKP:COLOR 7
490 COLOR 12:INPUT "NO OF CYCLES TO PERFORM <1> =
";NOFCYCLES:COLOR 7
500 IF NOFCYCLES <=0 THEN NOFCYCLES=1
510 LOCATE 23,1:GOSUB 900
520 '
530 IF MAN$="N" AND CYCLENO >= NOFCYCLES THEN COLOR 14:SOUND
1234,50:PRINT "!!END OF JOB!!":COLOR 7:CLOSE:END
540 BCNT=BCNT+1
550 PRINT
560 PRINT "************************************************"
570 PRINT
580 COLOR 9:PRINT "EXECUTING DATA FOR MOVE NO:";BCNT:COLOR
7:IF MAN$="N" THEN:COLOR 13:PRINT "CYCLE NO IS
"CYCLENO+1:COLOR 7
590 NOFSPL = 1
```

```
600 IF MAN$="N" THEN INDX=INDX+1:I1$(NOFSPL)=BRAIDATA$(INDX)
610 IF MAN$<>"N" THEN I1$(NOFSPL)=BRAIDATA$(NOFSPL)
620 IF I1$(NOFSPL)="E" THEN
CYCLENO=CYCLENO+1:NSKP=0:INDX=0:BCNT = 0:GOTO 520
630 IF I1$(NOFSPL)="0" THEN GOSUB 2110:GOTO 600
640 IF I1$(NOFSPL) >= "1" AND I1$(NOFSPL) <= NOFSPOOLS$ THEN
650 ELSE 670
650 NOFSPL = NOFSPL+1
660 GOTO 600
670 IF I1$(NOFSPL) <> "U" AND I1$(NOFSPL) <> "D" AND
I1$(NOFSPL) <> "R" AND I1$(NOFSPL) <> "L" THEN BEEP:COLOR
13:PRINT "ERROR IN DATA FILE!!":COLOR 7:STOP
680 DIRN$ = I1$(NOFSPL)
690 IF BCNT<=NSKP THEN 520
700 X$=CHR$(27)'Escape
710 'IF I1(4)<>0 THEN X$=INPUT$(1)
720 DONE$="N"
730 IF DIRN$="U" AND POSN$="HOME" THEN GOSUB 2030:ACYCLE =
1:ACOND=32:POSN$="UP":DONE$="Y":GOTO 850
740 IF DIRN$="U" AND POSN$="UP" THEN ACYCLE =
1:ACOND=4:POSN$="HOME":DONE$="N":GOTO 850
750 IF DIRN$="U" AND POSN$="RIGHT" THEN ACYCLE =
2:ACOND=4:POSN$="HOME":DONE$="N":GOTO 850
760 IF DIRN$="D" AND POSN$="UP" THEN GOSUB 2030:ACYCLE =
1:ACOND=4:POSN$="HOME":DONE$="Y":GOTO 850
770 IF DIRN$="D" AND POSN$="HOME" THEN ACYCLE =
1:ACOND=32:POSN$="UP":DONE$="N":GOTO 850
```

```
780 IF DIRN$="D" AND POSN$="RIGHT" THEN ACYCLE =
2:ACOND=4:POSN$="HOME":DONE$="N":GOTO 850
790 IF DIRN$="R" AND POSN$="HOME" THEN GOSUB 2030:ACYCLE =
2:ACOND=32:POSN$="RIGHT":DONE$="Y":GOTO 850
800 IF DIRN$="R" AND POSN$="UP" THEN ACYCLE =
1:ACOND=4:POSN$="HOME":DONE$="N":GOTO 850
810 IF DIRN$="R" AND POSN$="RIGHT" THEN ACYCLE =
2:ACOND=4:POSN$="HOME":DONE$="N":GOTO 850
820 IF DIRN$="L" AND POSN$="RIGHT" THEN GOSUB 2030:ACYCLE =
2:ACOND=4:POSN$="HOME":DONE$="Y":GOTO 850
830 IF DIRN$="L" AND POSN$="UP" THEN ACYCLE =
1:ACOND=4:POSN$="HOME":DONE$="N":GOTO 850
840 IF DIRN$="L" AND POSN$="HOME" THEN ACYCLE =
2:ACOND=32:POSN$="RIGHT":DONE$="N":GOTO 850
850 IF X$=CHR$(27)THEN PRINT:GOSUB 1280:GOSUB 1670:GOSUB
900:COND=SCOND:'Esc KEY
860 IF X$=CHR$(32)THEN GOSUB 900:'Space bar turns off all
Spools
870 IF DONE$="N" THEN 720
880 IF MAN$="N" THEN 520 ELSE CLS:LOCATE 8,1:BEEP:GOTO 170
890 '
900 COND=4:COND$="OFF":COLOR 7
910 FOR AD=125 TO 127:GOSUB 950:NEXT AD:'Turn off all Spools
920 RETURN
930 '
940 COND=32:COND$="ON":COLOR 12
950 A=AD+128
```

```
960 PRINT #1,CHR$(A);:PRINT #1,CHR$(COND);
970 GOSUB 1250:'WAIT
980 L=LOC(1):IF L=2 THEN BEEP:COLOR 10:PRINT"NO RESPONSE
FROM SPOOL #"AD-124:COLOR 7:STOP:GOSUB 1160:PRINT:RETURN 520
990 GOSUB 1160:'Clear input Buffer
1000 ID$=INPUT$(1,#1):ST$=INPUT$(1,#1)
1010 ID=ASC(ID$):ST=ASC(ST$)
1020 IF AD<>ID THEN 1080
1030 IF COND=32 AND ST<> 1 THEN 1100
1040 IF COND=4 AND ST<> 6 THEN 1100
1050 PRINT"SPOOL # "ID-124,COND$"      "
1060 RETURN
1070 '
1080 PRINT:FOR X=1000 TO 440 STEP -5:SOUND X,.1:NEXT X
1090 BEEP:COLOR 10:PRINT"SPOOL #"AD" ADDRESSING ERROR
"ID:COLOR 7:STOP
1100 PRINT:FOR X=1000 TO 440 STEP -10:SOUND X,.1:NEXT X
1110 BEEP:COLOR 10:PRINT"SPOOL #"AD" STATUS ERROR "ST:COLOR
7:STOP
1120 PRINT:FOR X=1000 TO 440 STEP -9:SOUND X,.1:NEXT X
1130 BEEP:COLOR 10:PRINT"COMMUNICATION LINE ERROR ":COLOR
7:STOP
1140 '
1150 REM    Clears Data from Input Buffer & Tests
Communication Line Error
1160 IDO$=INPUT$(1,#1):STO$=INPUT$(1,#1)
1170 IDO=ASC(IDO$):STO=ASC(STO$)
```

```
1180 IF A<>IDO THEN 1120
1190 IF COND<>STO THEN 1120
1200 RETURN
1210 '
1220 L=LOC(1):IF L=2 THEN BEEP:COLOR 29:PRINT"NO RESPONSE
FROM POWER CONTROL UNIT":COLOR 7:STOP
1230 RETURN
1240 '
1250 FOR T=0 TO 300:NEXT T:REM WAIT FOR RESPONSE **Orig 200
1260 RETURN
1270 '
1280 SCOND=COND:'** High Power Mode **
1290 PRINT #1,CHR$(128);:PRINT#1,CHR$(32);:'** High Power **
1300 A=128:COND=32:GOSUB 1220:'Check for Response
1310 GOSUB 1160:'Clear Input Buffer
1320 A=0:COND=5:GOSUB 1160
1330 '
1340 IF AUTOSEQ$="Y" OR AUTOSEQ$="y" THEN 1390
1350 COLOR 9:PRINT"PRESS ESCAPE KEY TO MOVE":COLOR 7
1360 IF INPUT$(1)=CHR$(27)THEN 1400
1370 IF INPUT$(1)=CHR$(32)THEN GOSUB 1490:GOTO 520
1380 GOTO 1360
1390 FOR T=0 TO 500:NEXT T:'Delay Before Move ***Orig 1250
1400 '
1410 PRINT
#1,CHR$(ACYCLE+128);:PRINT#1,CHR$(ACOND);:'**Move**
1420 GOSUB 1250:'Wait
```

```
1430 A=ACYCLE
1440 L=LOC(1):IF L<>2 THEN BEEP:COLOR 9:PRINT"NO RESPONSE
FROM AIR CYLINDER #"A:COLOR 7:GOSUB 1490:STOP
1450 GOSUB 1610:'Tests Air Cylinder Communication Line &
Status
1460 '
1470 FOR T=0 TO 100:NEXT T:'*** Spool Solenoid on Time
***Orig 300
1480 '
1490 PRINT #1,CHR$(128);:PRINT#1,CHR$(4);:'** Low Power **
1500 A=0:COND=2:GOSUB 1250:'A=128,COND=4 Without Power Shift
Relay Active
1510 GOSUB 1160:'Clear Input Buffer
1520 RETURN
1530 '
1540 IF (MAN$="Y" OR MAN$="y") AND (AUTOSEQ$ <> "Y" OR
AUTOSEQ$ <> "y") THEN 1550 ELSE 1570
1550 CLS:LOCATE 25,7
1560 COLOR 5:PRINT"PRESS SPOOL #/S TO BE ON & DIRECTION TO
MOVE THEN PRESS ESCAPE TO CYCLE":COLOR 7
1570 IF (MAN$="Y" OR MAN$="y") AND (AUTOSEQ$="Y" OR
AUTOSEQ$="y") THEN CLS:LOCATE 25,7:COLOR 5:PRINT "PRESS
SPOOL #/S TO BE ON & DIRECTION TO MOVE":COLOR 7
1580 LOCATE 1,1:RETURN
1590 '
1600 REM   Tests Air Cylinder Communication Line & Status
1610 IDO=ASC(INPUT$(1,#1)):STO=ASC(INPUT$(1,#1))
```

```
1620 IF A<>IDO THEN PRINT"AIR CYLINDER #"A:GOTO 1120
1630 IF STO=5 OR STO=13 OR STO=2 OR STO=10 THEN 1650
1640 AD=A:GOSUB 1490:GOTO 1100
1650 RETURN
1660 '
1670 '** Check Air Cylinder Limit Switch Status **
1680 IF ACYCLE=1 AND ACOND=32 THEN 1730
1690 IF ACYCLE=1 AND ACOND=4 THEN GOSUB 1930:RETURN
1700 IF ACYCLE=2 AND ACOND=32 THEN 1830
1710 IF ACYCLE=2 AND ACOND=4 THEN GOSUB 1930:RETURN
1720 '
1730 PRINT #1,CHR$(ACYCLE+128);:PRINT#1,CHR$(ACOND);:'**
POLL #1 **
1740 GOSUB 1250:A=ACYCLE+128:COND=32
1750 L=LOC(1):IF L<>4 THEN BEEP:COLOR 9:PRINT"NO RESPONSE
FROM AIR CYLINDER #1":COLOR 7:STOP
1760 GOSUB 1160:'Clear Input Buffer
1770 IDO=ASC(INPUT$(1,#1)):STO=ASC(INPUT$(1,#1))
1780 IF IDO<>1 THEN PRINT"AIR CYLINDER #1 ":GOTO 1120
1790 LOCATE 23,35
1800 IF STO=5 THEN PRINT"CYCLE "CYCLE$"           ":RETURN
1810 BEEP:COLOR 5:PRINT"MOVE UP NOT COMPLETE";:COLOR 7:GOTO
1730
1820 '
1830 PRINT #1,CHR$(ACYCLE+128);:PRINT#1,CHR$(ACOND);:'**
POLL #2 **
1840 GOSUB 1250:A=ACYCLE+128:COND=32
```

```
1850 L=LOC(1):IF L<>4 THEN BEEP:COLOR 3:PRINT"NO RESPONSE
FROM AIR CYLINDER #2":COLOR 7:STOP
1860 GOSUB 1160:'Clear Input Buffer
1870 IDO=ASC(INPUT$(1,#1)):STO=ASC(INPUT$(1,#1))
1880 IF IDO<>2 THEN PRINT"AIR CYLINDER #2 ":GOTO 1120
1890 LOCATE 23,35
1900 IF STO=5 THEN LOCATE 22,35:COLOR 6:PRINT"CYCLE "CYCLE$"
          ":COLOR 7:RETURN
1910 BEEP:COLOR 5:PRINT"MOVE RIGHT NOT COMPLETE";:COLOR
7:GOTO 1830
1920 '
1930 '*** CHECK FOR HOME LIMIT SWITCH ***
1940 PRINT #1,CHR$(3+128);:PRINT#1,CHR$(32);
1950 GOSUB 1250:'Wait
1960 L=LOC(1):IF L<>4 THEN BEEP:COLOR 3:PRINT"NO RESPONSE
FROM HOME LIMIT SWITCH":COLOR 7:STOP
1970 A=3+128:COND=32:GOSUB 1160
1980 IDO=ASC(INPUT$(1,#1)):STO=ASC(INPUT$(1,#1))
1990 IF IDO<>3 THEN COLOR 10:PRINT"HOME LIMIT SWITCH":COLOR
7:GOTO 1120
2000 LOCATE 23,35
2010 IF STO=5 THEN LOCATE 23,35:COLOR 6:PRINT"CYCLE "CYCLE$"
          ":COLOR 7:RETURN
2020 BEEP:LOCATE 24,12:COLOR 9:PRINT"NOT HOME (SET THE
SYSTEM TO HOME POSITION AND CONTINUE) ";:COLOR 7:GOTO 70
2030 '
2040 FOR II=1 TO NOFSPL-1
```

```
2050 Y$=I1$(II)

2060 AD = 124+ASC(Y$)-48

2070 GOSUB 940

2080 Y$=CHR$(32)

2090 NEXT II

2100 RETURN

2110 'Delay Interrupt Routine

2120 COLOR 25:LOCATE 24,7:PRINT "PRESS ANY KEY TO
CONTINUE":BEEP:COLOR 7

2130 A$=INKEY$: IF A$="" THEN 2130

2140 RETURN
```

MODIFIED FARLEY BRAIDER PROGRAM

```
10 '*************** BRAIDER PROGRAM HEADER ****************
BRAIDER.HDR
20 'PIO 24 ADDRESSES:
30 '    PORT A => 300H ; USED FOR FEEDBACK INPUT
40 '    PORT B => 301H ; USED FOR DIRECTION, COLUMN AND ROW
SELECT OUTPUT
50 '    PORT C => 302H ; USED FOR FB COL SEL, ROTATE TABLE &
ENABLE OUTPUT
60 '    CONTROL PORT => 303H
70 '            CONTROL PORT BITS:
80 '                  BITS D7-D5 & D2 ARE NOT USED
90 '                  BIT D4 => 0 => PORT A OUT
100 '                           1 => PORT A IN              X
110 '                 BIT D3 => 0 => PORT C BITS 4 - 7 OUT X
120 '                           1 => PORT C BITS 4 - 7 IN
130 '                 BIT D1 => 0 => PORT B OUT              X
140 '                           1 => PORT B IN
150 '                 BIT D0 => 0 => PORT C BITS 0 - 3 OUT X
160 '                           1 => PORT C BITS 0 - 3 IN
170 '   CONTROL WORD 00010000B, 10H, 16D FOR SETUP MARKED
WITH "X"
180 '
190 '   PORT B DATA CONSTRUCTION
200 '           PORTB.DATA% = PORTB.DATA% AND FREQUENCY%(N)
210             PORTB.DATA% = PORTB.DATA% AND ROW.SEL%
220             PORTB.DATA% = PORTB.DATA% AND COL.SEL%
230 '   PORT C DATA CONSTRUCTION
```

```
240 '              PORTC.DATA% = PORTC.DATA% AND FB.COL%
250                PORTC.DATA% = PORTC.DATA% AND DIRECTION%
260                PORTC.DATA% = PORTC.DATA% AND FEEDBACK%
270                PORTC.DATA% = PORTC.DATA% AND EMITTER%
280 '
290 'NAMES:
300 '    PORTA.DATA% => FEEDBACK DATA; ONE BIT AT SELECTED
ROW AND COLUMN
310 '    PORTB.DATA% => DATA TO BE OUTPUT ON PORT B
320 '    PORTC.DATA% => DATA TO BE OUTPUT ON PORT C
330 '    PORTA.ADDR% => PORT A ADDRESS; 300H
340 '    PORTB.ADDR% => PORT B ADDRESS; 301H
350 '    PORTC.ADDR% => PORT C ADDRESS; 302H
360 '    EMITTER%     => 'AND' MASK.  SET = EMITTER.ON% OR
EMITTER.OFF%
370 '    EMITTER.ON% => 'AND' MASK = &H7F TO TURN EMITTERS ON
380 '    EMITTER.OFF%=> 'AND' MASK = &HFF TO TURN EMITTERS
OFF
390 '    FEEDBACK%    => 'AND' MASK.  SET = FEEDBACK.ON% OR
FEEDBACK.OFF%
400 '    FEEDBACK.ON%=> 'AND' MASK = &HF3 TO ENABLE FEEDBACK
410 '    FEEDBACK.OFF% => 'AND' MASK = &HFF TO IGNORE
FEEDBACK
420 '    ROW.COL%(N) => ROW/COL FORMAT FOR INPUTTING INITIAL
POSITIONS AND
430 '                       DESTINATION DATA FOR EACH BUGGY
440 '    ROW.DEST%    => TEMPORARY 'AND' MASK.  SET = ROW%(N)
```

```
450 '    ROW%(N)        => 'AND' MASK ARRAY FOR OR ROW.DEST%
460 '    FB.ROW%        => 'AND' MASK.  SET = ROW.DEST%
470 '    ROW.NOW%       => PRESENT ROW LOCATION OF BUGGY
480 '    COL.DEST%      => TEMPORARY 'AND' MASK.  SET = COL%(N)
490 '    COL%(N)        => 'AND' MASK ARRAY FOR OR COL.DEST%
500 '    FB.COL%        => 'AND' MASK.  SET = COL.DEST%
510 '    COL.NOW%       => PRESENT COLUMN LOCATION OF BUGGY
520 '                      e.g. AT END OF MOVE, SET ROW.NOW% =
ROW.DEST% TO UPDATE
530 '    DIRECTION%     => 'AND' MASK.  SET = XDIR% OR YDIR%
540 '    XDIR%          => 'AND' MASK = &HEF TO ROTATE TABLE TO
+/- X DIRECTION
550 '    YDIR%          => 'AND' MASK = &HFF TO ROTATE TABLE TO
+/- Y DIRECTION
560 '    FREQUENCY%(N)  => 'AND' MASK.  SET = POSITIVE%,
NEGATIVE% OR DEST%
570 '    POSITIVE%      => 'AND' MASK = &H7F TO SELECT POSITIVE
DIRECTION
580 '    NEGATIVE%      => 'AND' MASK = &HBF TO SELECT NEGATIVE
DIRECTION
590 '    DEST%          => 'AND' MASK = &H3F TO STOP (AT
DESTINATION)
600 '*************** SET CONSTANTS **************
CONSTANT.SET
610      CLS
620      PORTA.ADDR% = &H300
630      PORTB.ADDR% = &H301
```

```
640     PORTC.ADDR% = &H302
650     CONTROL.PORT% = &H303
660     CONTROL.WORD% = &H10
670 '************** SET MASKS ************** MASK.SET
680     DIM ROW%(10)
690     DIM COL%(10)
700     DIM ROW.COL%(10)
710     DIM ROW.NOW%(10)
720     DIM COL.NOW%(10)
730     DIM ROW.DEST%(10)
740     DIM COL.DEST%(10)
750     DIM BRAIDATA(1000)
760     DIM ROW.MASK%(10)
770     DIM COL.MASK%(10)
780     DIM FREQUENCY%(10)
790     DIM MOTION$(10)
800     PORTA.DATA% = &HFF
810     PORTB.DATA% = &HFF
820     PORTC.DATA% = &HFF
830     EMITTER.ON% = &H7F
840     EMITTER.OFF% = &HFF
850     FEEDBACK.ON% = &HF7
860     FEEDBACK.OFF% = &HFF
870     XDIR% = &HFF
880     YDIR% = &HBF
890     POSITIVE% = &H7F
900     NEGATIVE% = &HBF
```

```
910     DEST% = &H3F
920     ROW%(0) = &HC7
930     ROW%(1) = &HCF
940     ROW%(2) = &HD7
950     ROW%(3) = &HDF
960     ROW%(4) = &HE7
970     COL%(0) = &HF8
980     COL%(1) = &HF9
990     COL%(2) = &HFA
1000     COL%(3) = &HFB
1010     COL%(4) = &HFC
1020     COL%(5) = &HFD
1030     ROW.FIX% = 5
1040 '****************** INITIALIZE *******************
1050 '
1060 '
1070 'SET-UP PORTS FOR INPUT AND OUTPUT AS PRESCRIBED IN
HEADER
1080 '
1090  OUT CONTROL.PORT%,CONTROL.WORD%
1100 '
1110 'SET-UP PORT C
1120 'SELECT UN-USED COLUMN FOR FEEDBACK, ENABLE FEEDBACK,
ENABLE EMITTERS
1130 'AND ROTATE TABLE TO +/- X DIRECTION
1140 '
1150  FB.COL% = COL%(5)
```

```
1160  FEEDBACK% = FEEDBACK.ON%
1170  EMITTER% = EMITTER.ON%
1180  DIRECTION% = XDIR%
1190 CYCLENO = 1
1200 MOVENO =  1
1210 KEY(1) ON:ON KEY(1) GOSUB 3470
1220 COLOR 25:LOCATE 5,20:PRINT "PRESS F1 TO PAUSE ANY
TIME":COLOR 7
1230 LOCATE 10,5:COLOR 3:PRINT "PROGRAM INITIALIZATION"
1240  PRINT
1250  COLOR 5:PRINT "PORT B DATA SHOULD BE '101' FOR
INITIALIZATION "
1260  PRINT
1270  PRINT "TO DETERMINE WHETHER DATA IS CORRECT OR NOT, "
1280  PRINT "CONVERT PORT B DATA OR PORT C DATA TO BINARY "
1290  PRINT "AND COMPARE TO CHART "
1300  PRINT
1310  PRINT
1320  GOSUB 3230:' PORT C OUTPUT SUBROUTINE
1330  FOR I=1 TO 1000:NEXT I
1340  COLOR 5:PRINT "PLEASE PRESS ";:COLOR 3:PRINT "ENTER
";:COLOR 5: INPUT "IF YOU WANT TO CONTINUE ";Q$
1350 CLS:LOCATE 10,5:COLOR 6:PRINT "TABLE SHOULD BE ORIENTED
IN THE DEFAULT ";:COLOR 3:PRINT "+/- X ";:COLOR 6:PRINT
"DIRECTION "
1360 PRINT
1370 COLOR 2:INPUT "IS THIS CORRECT <Y> ";A$
```

```
1380 PRINT
1390  IF A$ <> "N" AND A$ <> "n" THEN A$ = "Y"
1400  IF A$ = "n" OR A$ = "N" THEN A$ = "N"
1410  LOCATE 14,1:COLOR 4:IF A$ = "N" THEN PRINT "PLEASE PUT
THE TABLE IN THE DEFAULT DIRECTION AND PRESS ";:COLOR
3:PRINT "ENTER ";:COLOR 4:INPUT "TO CONTINUE ";A$:IF A$=""
THEN GOTO 1350
1420 '
1430 'ENTER INITIAL BUGGY POSITIONS
1440 '
1450 CLS:LOCATE 10,5:COLOR 3:INPUT "ARE BUGGIES CURRENTLY
LOADED ON BRAIDER FRAME <Y> ";BUGGYON$
1460 IF BUGGYON$ <> "N" AND BUGGYON$ <> "n" THEN BUGGYON$ =
"Y"
1470 IF BUGGYON$ = "N" OR BUGGYON$ = "n" THEN BUGGYON$ = "N"
1480  PRINT
1490  A$ = "Y"
1500  FOR N = 1 TO 3
1510  IF A$ = "N" THEN CLS:COLOR 3:LOCATE 8,10:PRINT "PLEASE
GIVE THE CORRECT BUGGY POSITIONS THIS TIME "
1520  IF A$ = "N" THEN COLOR 4:LOCATE 10,15:INPUT "PLEASE
PRESS ENTER TO CONTINUE ";Q$
1530  IF BUGGYON$ = "Y" THEN CLS:LOCATE 10,5:COLOR 2:PRINT
"PLEASE ENTER INITIAL POSITION FOR BUGGY NUMBER ";:COLOR
3:PRINT N
1540  IF BUGGYON$ = "N" THEN CLS:LOCATE 10,5:COLOR 2:PRINT
"PLEASE SPECIFY THE INITIAL DESTINATION FOR THE BUGGY NUMBER
```

```
";:COLOR 3:PRINT N
1550  PRINT
1560  IF BUGGYON$ = "Y" THEN COLOR 5:PRINT "PLEASE ENTER
INITIAL BUGGY POSITION IN THE FOLLOWING FORMAT "
1570  IF BUGGYON$ = "N" THEN COLOR 5:PRINT "PLEASE ENTER
INITIAL BUGGY DESTINATION IN THE FOLLOWING FORMAT "
1580  PRINT
1590  COLOR 6:PRINT "THE SAMPLE FORMAT IS ";:COLOR 3:INPUT
"34 => ROW 3, COLUMN 4  ";ROW.COL%(N)
1600  ROW.DEST%(N)= ROW.COL%(N) / 10
1610  ROW.NOW%(N) = ROW.DEST%(N)
1620  ROW.MASK%(N) = ROW%(ROW.DEST%(N))
1630  COL.DEST%(N)= 10 * (ROW.COL%(N) / 10 - ROW.DEST%(N))
1640  COL.NOW%(N) = COL.DEST%(N)
1650  COL.MASK%(N) = COL%(COL.DEST%(N))
1660  PRINT
1670  COLOR 5:PRINT "ROW DESTINATION IS    ";:COLOR 3:PRINT
ROW.DEST%(N)
1680  COLOR 5:PRINT "COLUMN DESTINATION IS ";:COLOR 3:PRINT
COL.DEST%(N)
1690  PRINT
1700  COLOR 2:INPUT "IS THIS CORRECT <Y> ";A$
1710  IF A$ <> "N" AND A$ <> "n" THEN A$ ="Y"
1720  IF A$ = "n" THEN A$ = "N"
1730  IF A$ = "N" THEN GOTO 1510
1740 FREQUENCY%(N) = DEST%
1750    ROW.MASK%(N) = ROW.MASK%(N)
```

```
1760     COL.MASK%(N) = COL.MASK%(N)
1770   GOSUB 3150:' ********* PORT B OUTPUT SUBROUTINE
********
1780     FB.COL% = COL.MASK%(N)
1790     FEEDBACK% = FEEDBACK.ON%
1800     EMITTER% = EMITTER.ON%
1810     DIRECTION% = XDIR%
1820   GOSUB 3230:' PORT C OUTPUT SUBROUTINE
1830   FOR I=1 TO 1000:NEXT I
1840     PRINT
1850   IF BUGGYON$ = "N" THEN CLS:LOCATE 10,5:PRINT "STOP
FREQUENCY WILL BE SET AT BUGGY POSITION "
1860   PRINT
1870   IF BUGGYON$ = "N" THEN COLOR 4:PRINT "START BUGGY
MOTOR IN THE PROPER DIRECTION WITH AN EXTERNAL "
1880   IF BUGGYON$ = "N" THEN PRINT "EMITTER AND INSERT INTO
THE BRAIDER MATRIX IN THE PROPER ROW "
1890   IF BUGGYON$ = "N" THEN PRINT:COLOR 5:PRINT "BUGGY WILL
STOP AT ITS DESTINATION - IF NOT, TURN POWER OFF "
1900   PORTA.DATA% = INP(PORTA.ADDR%)
1910   TEMP% = &HFF - 2^ROW.FIX%
1920   IF PORTA.DATA% <> TEMP% THEN GOTO 1900
1930   PRINT
1940   LOCATE 22,5:COLOR 2:PRINT "FEEDBACK RECEIVED - PRESS
";:COLOR 3:PRINT "ENTER ";:COLOR 2:INPUT "TO CONTINUE ";Q$
1950   NEXT N
1960 CLS:LOCATE 8,11:COLOR 3:INPUT "DO YOU WANT TO RUN THE
```

```
MACHINE IN MANUAL MODE <N> ";MAN$
1970 IF MAN$ ="Y" OR MAN$ = "y" THEN MAN$ = "Y"
1980 IF MAN$ <> "Y" AND MAN$ <> "y" THEN MAN$ = "N"
1990 PRINT
2000 IF MAN$ = "N" THEN COLOR 2:INPUT "INPUT THE NO. OF
CYCLES NEEDED <1> ";NOFCYCLES
2010 IF NOFCYCLES <= 1 THEN NOFCYCLES = 1
2020 PRINT
2030 IF MAN$ = "N" THEN INPUT "DO YOU WANT TO SKIP STEPS <N>
";SKIP$
2040 IF SKIP$ <> "Y" AND SKIP$ <> "y" THEN SKIP$ = "N"
2050 PRINT
2060 IF SKIP$ = "y" OR SKIP$ = "Y" THEN SKIP$ = "Y":IF SKIP$
= "Y" THEN INPUT "INPUT STEPS TO SKIP ";SKIPNO
2070 IF SKIP$ = "Y" AND SKIPNO <= 1 THEN SKIPNO = 1
2080 IF SKIP$ = "Y" THEN KOUNT = SKIPNO * 3
2090 IF MAN$ = "N" THEN GOTO 2100 ELSE GOTO 2160
2100 OPEN "FARLEY.DAT" FOR INPUT AS #1
2110 INDX = 0
2120 WHILE NOT EOF(1):INDX=INDX+1:INPUT#1, BRAIDATA(INDX)
2130 WEND
2140 INDX=INDX+1:BRAIDATA(INDX) = 5
2150 CLOSE (1)
2160 '****************** MAIN PROGRAM *****************
2170 CLS
2180 IF SKIP$ = "Y" THEN MOVENO = SKIPNO + 1:GOTO 2210
2190 CLS:LOCATE 10,5:COLOR 3:INPUT "PLEASE PRESS ENTER TO
```

```
CONTINUE ";Q$
2200 KOUNT=0
2210 PRINT
2220 IF MAN$ = "N" OR MAN$ = "n" THEN GOTO 2330
2230 FOR N = 1 TO 3
2240 CLS:LOCATE 10,5:COLOR 4:PRINT "BUGGY";:COLOR 5:PRINT
N;:COLOR 4:PRINT "IS NOW AT ROW";:COLOR 3:PRINT
ROW.NOW%(N);:COLOR 4:PRINT "AND COLUMN";:COLOR 3:PRINT
COL.NOW%(N)
2250 PRINT
2260 COLOR 2:INPUT "DO YOU WANT TO MOVE THIS BUGGY <Y>";A$
2270 IF A$ <> "N" AND A$ <> "n" THEN A$ = "Y"
2280 IF A$ = "n" THEN A$ = "N"
2290 IF A$ = "N" THEN ROW.COL%(N)=ROW.COL%(N):GOTO 2310
2300 CLS:LOCATE 10,5:COLOR 5:PRINT "ENTER DESTINATION FOR
BUGGY NUMBER";:COLOR 3:PRINT N ;:INPUT ROW.COL%(N)
2310 NEXT N
2320 IF MAN$ = "Y" THEN GOTO 2390
2330 IF MAN$ = "N" AND BRAIDATA(KOUNT+1)=5 THEN CYCLENO =
CYCLENO+1:MOVENO = 1:GOTO 2200
2340 IF MAN$ = "N" AND CYCLENO > NOFCYCLES THEN FAULT$="END
OF JOB!":GOTO 3360
2350 IF MAN$ = "N" THEN 2360
2360 FOR N = 1 TO 3
2370 KOUNT = KOUNT+1:ROW.COL%(N)=BRAIDATA(KOUNT)
2380 NEXT N
2390 FOR N=1 TO 3:ROW.DEST%(N) = ROW.COL%(N) / 10
```

```
2400 COL.DEST%(N) = 10 * (ROW.COL%(N) / 10 - ROW.DEST%(N))
2410 NEXT N
2420 PRINT
2430 FOR N=1 TO 3
2440 IF ROW.NOW%(N) <> ROW.DEST%(N) THEN DIRECTION% = YDIR%
2450 IF COL.NOW%(N) <> COL.DEST%(N) THEN DIRECTION% = XDIR%
2460 NEXT N
2470 GOSUB 3230:'PORT C SUBROUTINE
2480  FOR I=1 TO 1000:NEXT I
2490 PRINT "MOVE NO IS ";:PRINT MOVENO;:PRINT "      ";:PRINT
"CYCLE NO IS ";:PRINT CYCLENO
2500 FOR N=1 TO 3
2510 ROW.MASK%(N) = ROW%(ROW.NOW%(N))
2520 COL.MASK%(N) = COL%(COL.NOW%(N))
2530 IF DIRECTION% = XDIR% THEN GOTO 2630
2540 ROW.DIST% = ROW.DEST%(N) - ROW.NOW%(N)
2550 IF ROW.DIST% < 0 THEN FREQUENCY%(N) = NEGATIVE%
2560 IF ROW.DIST% > 0 THEN FREQUENCY%(N) = POSITIVE%
2570 PRINT
2580 IF FREQUENCY%(N) = DEST% THEN MOTION$(N) = "STOP"
2590 IF FREQUENCY%(N) = POSITIVE% THEN MOTION$(N) =
"POSITIVE"
2600 IF FREQUENCY%(N) = NEGATIVE% THEN MOTION$(N) =
"NEGATIVE"
2610 COLOR 5:PRINT "MOTION = ";:COLOR 3:PRINT MOTION$(N)
2620 GOTO 2700
2630 COL.DIST% = COL.DEST%(N) - COL.NOW%(N)
```

```
2640 IF COL.DIST% < 0 THEN FREQUENCY%(N) = NEGATIVE%
2650 IF COL.DIST% > 0 THEN FREQUENCY%(N) = POSITIVE%
2660 IF FREQUENCY%(N) = DEST% THEN MOTION$(N) = "STOP"
2670 IF FREQUENCY%(N) = POSITIVE% THEN MOTION$(N) =
"POSITIVE"
2680 IF FREQUENCY%(N) = NEGATIVE% THEN MOTION$(N) =
"NEGATIVE"
2690 COLOR 5:PRINT "MOTION = ";:COLOR 3:PRINT MOTION$(N)
2700 NEXT N
2710 FOR N= 1 TO 3
2720 GOSUB 3150:' PORT B OUTPUT SUBROUTINE
2730 GOSUB 3320:' DELAY SUBROUTINE
2740 NEXT N
2750 FOR N = 1 TO 3
2760 FREQUENCY%(N) = DEST%
2770 ROW.MASK%(N) = ROW%(ROW.DEST%(N))
2780 COL.MASK%(N) = COL%(COL.DEST%(N))
2790 FB.COL% = COL.MASK%(N)
2800 NEXT N
2810 MOVENO = MOVENO + 1
2820 FOR N=1 TO 3
2830 MOTION$(N) = "STOP"
2840 COLOR 5:PRINT "MOTION = ";:COLOR 3:PRINT MOTION$(N)
2850 NEXT N
2860 FOR I = 1 TO 325
2870 N = I MOD 3 + 1
2880 GOSUB 3150:' PORT B OUTPUT SUBROUTINE
```

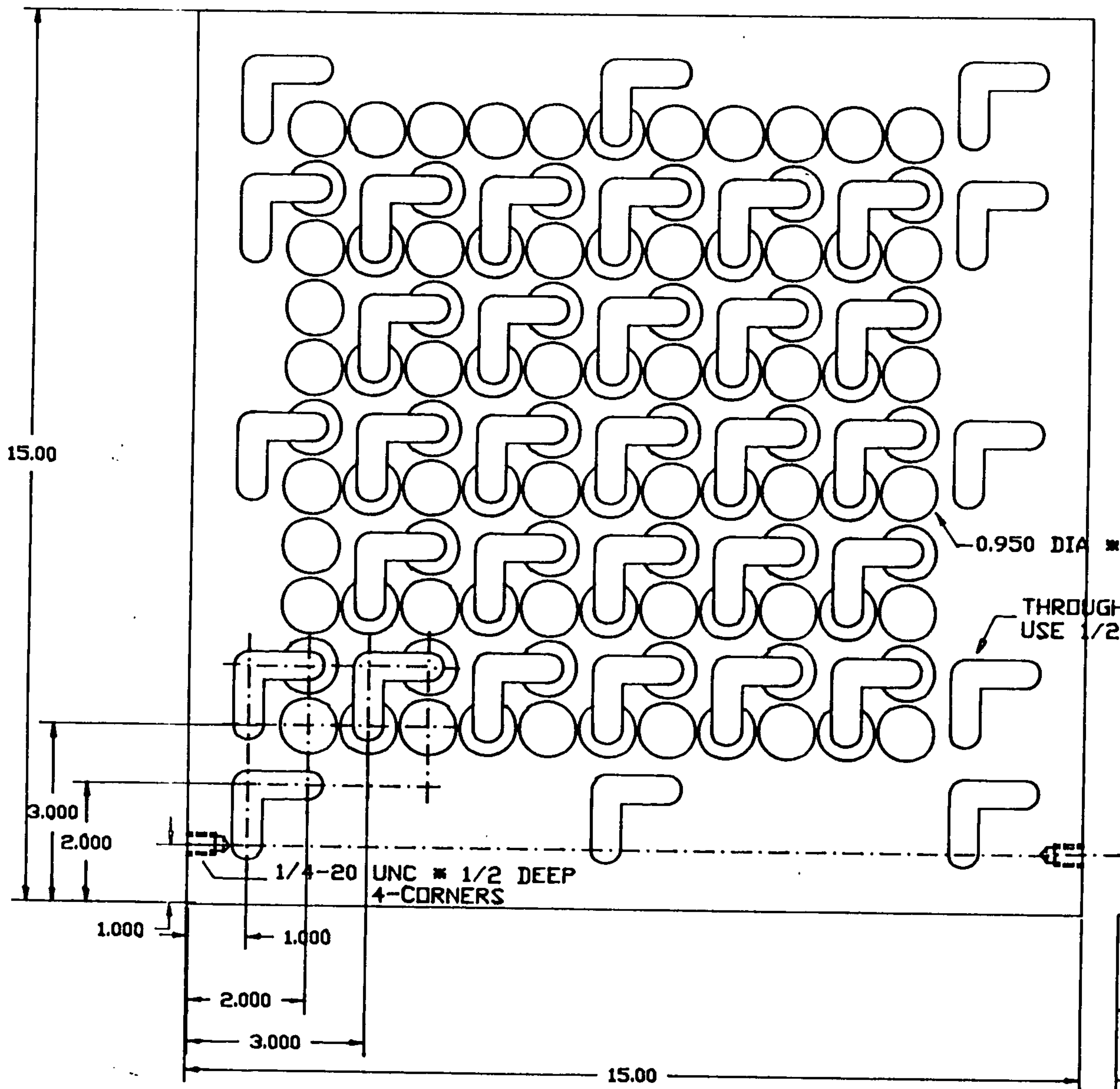
```
2890 FOR K=1 TO 5:NEXT K

2900 NEXT I

2910 CLS

2920 FOR N = 1 TO 3

2930 GOSUB 3230 :'PORT C OUTPUT SUBROUTINE

2940  FOR I=1 TO 1000:NEXT I

2950 PORTA.DATA% = INP(PORTA.ADDR%)

2960 TEMP% = &HFF - 2^ROW.FIX%

2970 IF PORTA.DATA% <> TEMP% THEN GOTO 2950

2980 PRINT

2990 ROW.NOW%(N) = ROW.DEST%(N)

3000 COL.NOW%(N) = COL.DEST%(N)

3010 NEXT N

3020 IF MAN$ = "Y" THEN COLOR 4:CLS:LOCATE 10,5:PRINT
"BUGGIES SHOULD STOP AT RESPECTIVE DESTINATIONS - IF NOT
TURN POWER 'OFF' "

3030 PRINT

3040 IF MAN$ = "Y" THEN COLOR 5:PRINT "FEEDBACK RECEIVED -
PRESS ";:COLOR 3:PRINT "ENTER ";:COLOR 5:INPUT "TO CONTINUE
";Q$

3050 CLS

3060 CLS

3070 IF MAN$ = "Y" THEN LOCATE 10,5:COLOR 2:INPUT "DO YOU
WANT TO CONTINUE IN MANUAL MODE <Y> ";A$

3080 IF MAN$ = "Y" THEN GOTO 3100

3090 IF MAN$ = "N" THEN A$ = "Y"

3100 IF A$ <> "N" AND A$ <> "n" THEN A$ = "Y"
```

```
3110 IF A$ = "Y" THEN GOTO 2220
3120 IF A$ = "n" THEN A$ = "N"
3130 IF A$ = "N" THEN FAULT$ = "OPERATOR TERMINATION"
3140 IF A$ = "N" THEN GOTO 3360
3150 '*********** PORT B OUTPUT SUBROUTINE **********
3160 '
3170  PORTB.DATA% = &HFF
3180  PORTB.DATA% = PORTB.DATA% AND FREQUENCY%(N)
3190  PORTB.DATA% = PORTB.DATA% AND ROW.MASK%(N)
3200  PORTB.DATA% = PORTB.DATA% AND COL.MASK%(N)
3210  OUT PORTB.ADDR%,PORTB.DATA%
3220  RETURN
3230 '*********** PORT C OUTPUT SUBROUTINE **********
PORTC.OUT
3240 '
3250  PORTC.DATA% = &HFF
3260  PORTC.DATA% = PORTC.DATA% AND FEEDBACK%
3270  PORTC.DATA% = PORTC.DATA% AND EMITTER%
3280  PORTC.DATA% = PORTC.DATA% AND FB.COL%
3290  PORTC.DATA% = PORTC.DATA% AND DIRECTION%
3300  OUT PORTC.ADDR%,PORTC.DATA%
3310  RETURN
3320 '************* DELAY SUBROUTINE ****************
3330  FOR K = 1 TO 200
3340  NEXT K
3350  RETURN
3360 '****************** PROGRAM END ****************
```

```
3370  CLS
3380  OPEN "LOCATION.END" FOR OUTPUT AS #3
3390  FOR N = 1 TO 3
3400  WRITE#3,N,ROW.NOW%(N),COL.NOW%(N)
3410  NEXT N
3420  CLOSE
3430  ' ********************************************
3440  LOCATE 10,10
3450  SOUND 1324,25:COLOR 12:PRINT "PROGRAM IS TERMINATED
DUE TO ";FAULT$
3460  END
3470 '************* DELAY INTERRUPT ROUTINE **********
3480 COLOR 25:CLS:LOCATE 9,20:PRINT "PRESS ANY KEY TO
CONTINUE":BEEP:COLOR 7
3490 A$=INKEY$:IF A$="" THEN 3490
3500 RETURN
```

Appendix E:

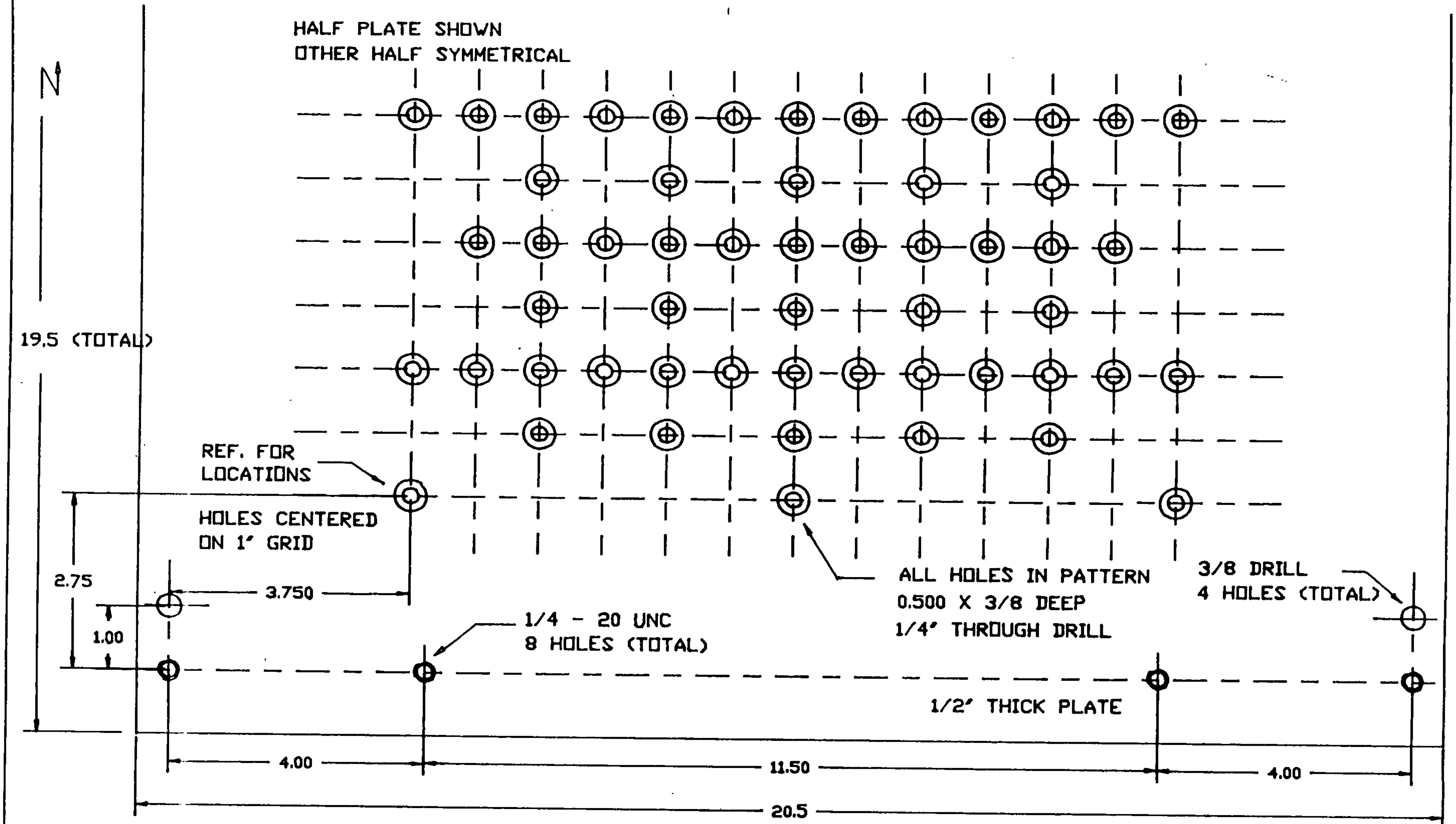
Electrical and Mechanical Drawings



SHUTTLE PLATE DETAIL
MAT'L: 1/2' ALUM. PLATE

ONE REQ'D

DEPARTMENT OF MECHANICAL ENGINEERING CLEMSON UNIVERSITY CLEMSON, SC
NASA - LANGLEY RESEARCH CENTER CO-OPERATIVE AGREEMENT NCC1-128
DRAWING: SHUTTLE PLATE BRAIDER - SHUTTLE PLATE
DRAWN BY:
DATE: FILE: M1SPLATE.DWG

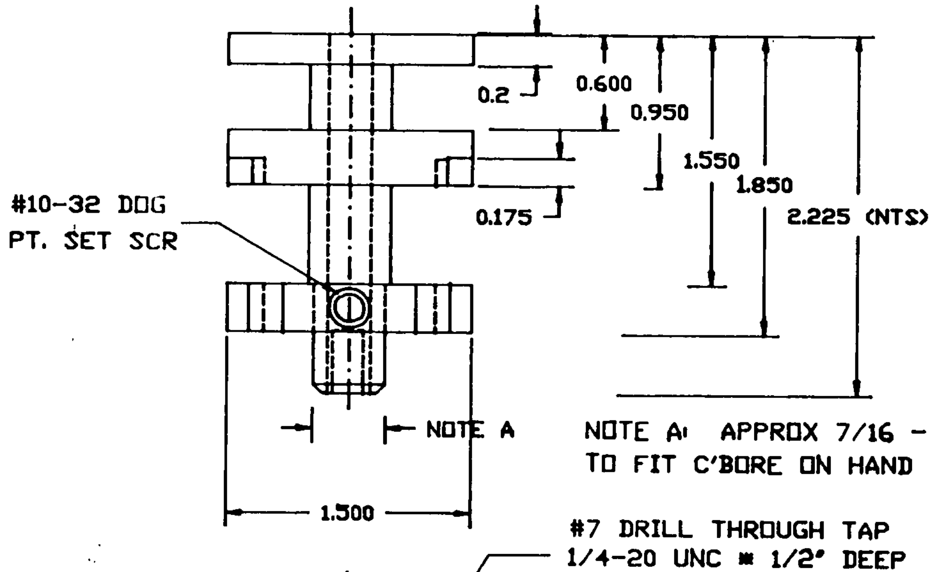


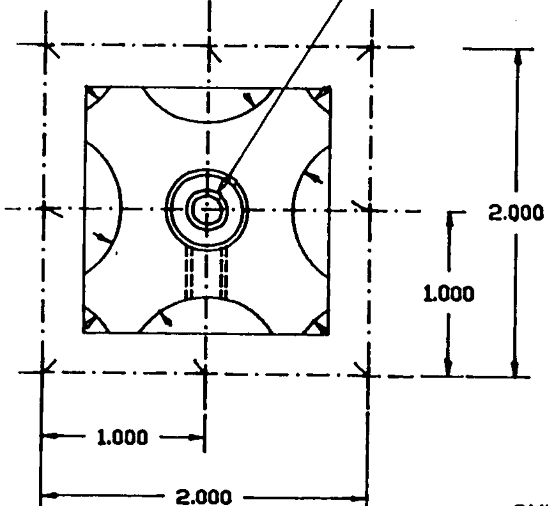
BASE PLATE

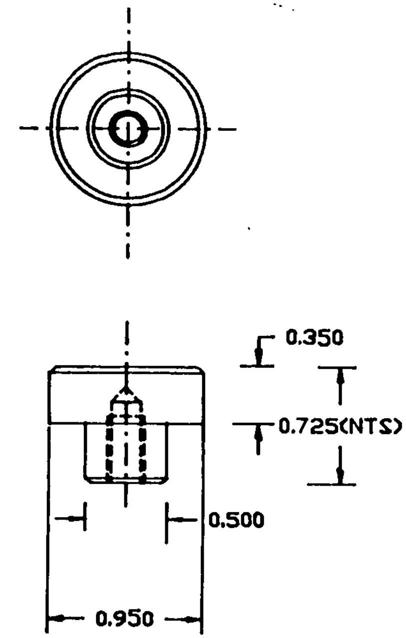
MAT'L: ALUMINUM (1/2" PLATE)

NO. REQ'D: 1

DEPARTMENT OF MECHANICAL ENGINEERING CLEMSON UNIVERSITY CLEMSON, SC	
NASA - LANGLEY RESEARCH CENTER CO-OPERATIVE AGREEMENT NCC1-128	
DRAWING: SHUTTLE PLATE BRAIDER - BASE PLATE	
DRAWN BY:	
DATE:	FILE: M1BASEPLATE.DWG







INDEXING & BRG. PLUG
MAT'L: DELRIN

NO REQD.: 30

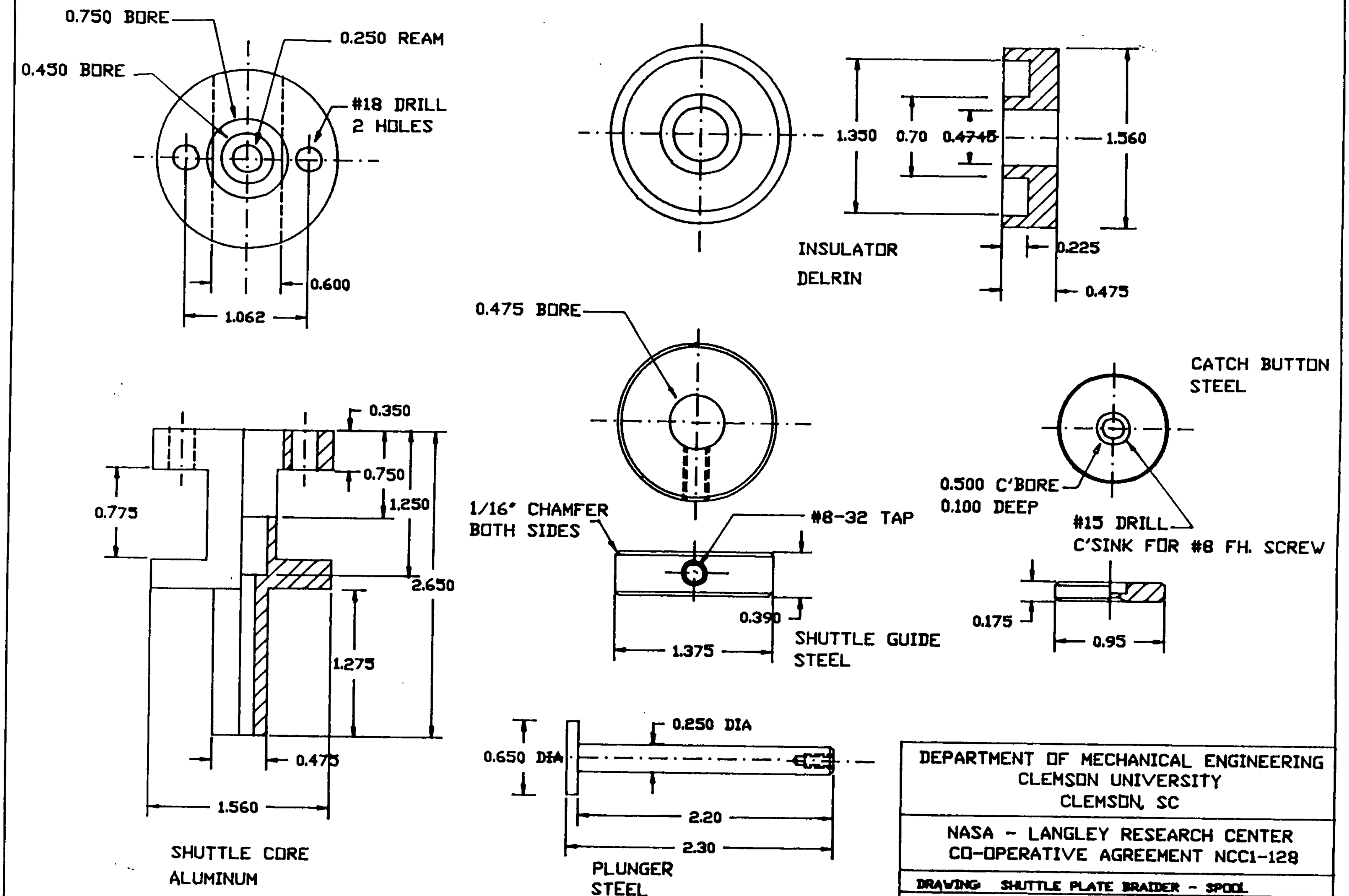
ALL RADII 0.475"
UNLESS OTHERWISE NOTED

ALL CHAMFERS 1/16" APPROX.

SURFACE ELEMENT
MAT'L: ALUMINUM

NO REQ'D: 25

DEPARTMENT OF MECHANICAL ENGINEERING CLEMSON UNIVERSITY CLEMSON, SC	
NASA - LANGLEY RESEARCH CENTER CO-OPERATIVE AGREEMENT NCC1-128	
DRAWING: SHUTTLE PLATE BRAIDER - ELEMENT	
DRAWN BY:	
DATE:	FILE: MIELEMENT.DWG



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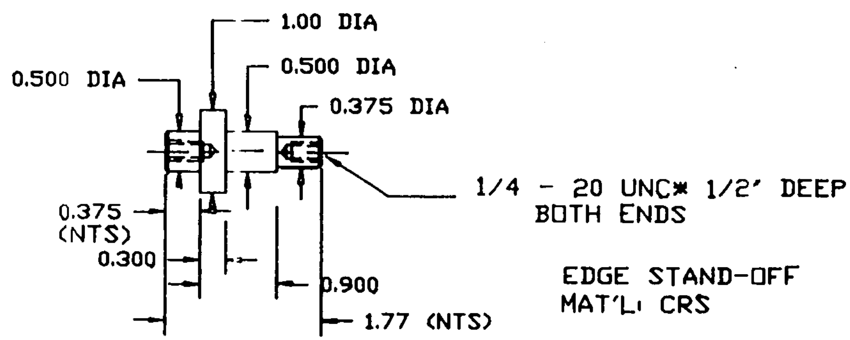
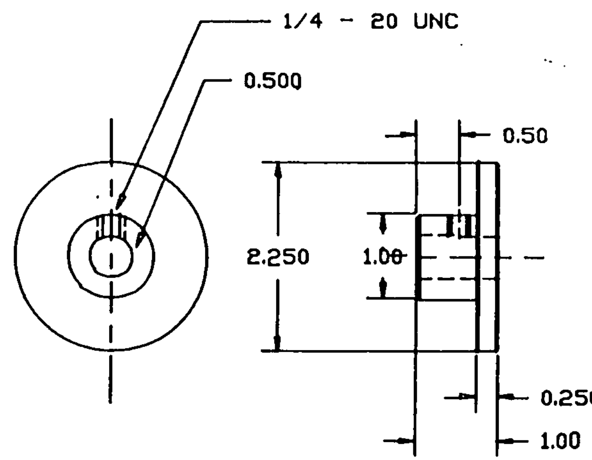
DRAWING: SHUTTLE PLATE BRAIDER - SPOOL
DRAWN BY:
DATE: FILE: M1SPOOL.DWG



EDGE STAND-OFF
MAT'L: CRS

NO. REQ'D: 12

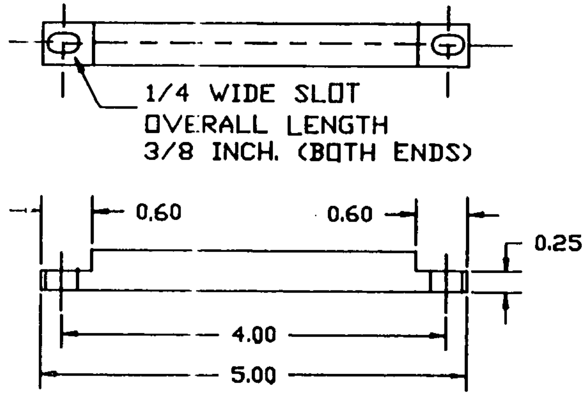


GUIDE FLANGE
MAT'L: CRS

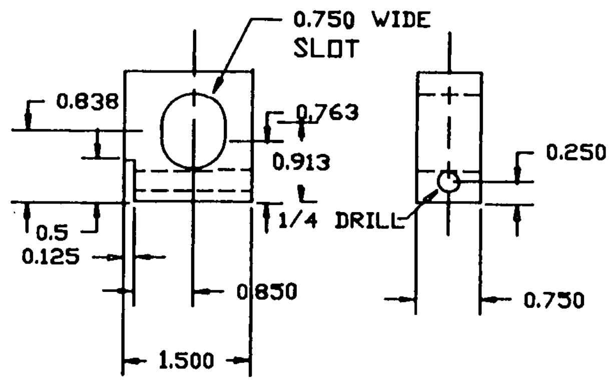
NO. REQ'D: 4

GUIDE RACK
MAT'L: STEEL

NO. REQ'D: 4

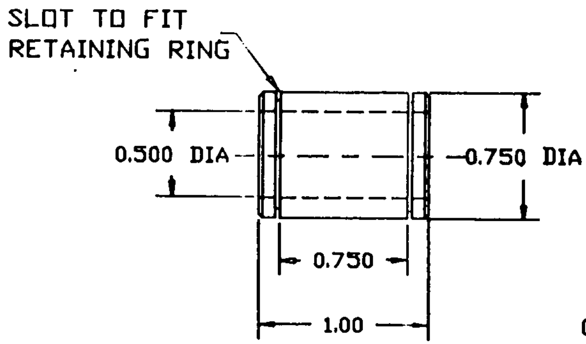


16 PITCH RACK
BOSTON GEAR # L512-4



BEARING BLOCK
MAT'L: ALUMINUM

NO. REQ'D: 4



CHAMFER
TO SUIT

GUIDE BUSHING
MAT'L: BRASS (OR BRONZE)

NO. REQ'D: 4

DEPARTMENT OF MECHANICAL ENGINEERING CLEMSON UNIVERSITY CLEMSON, SC	
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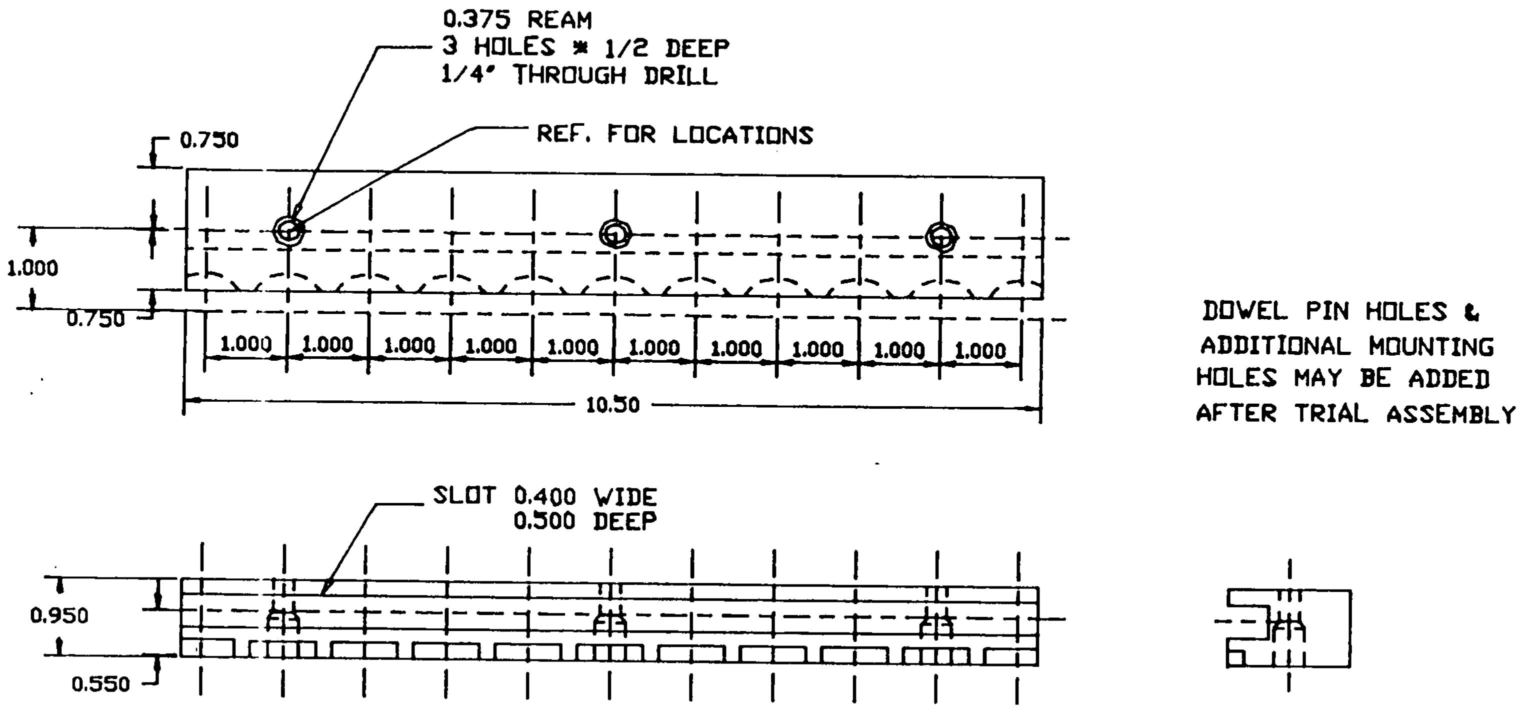
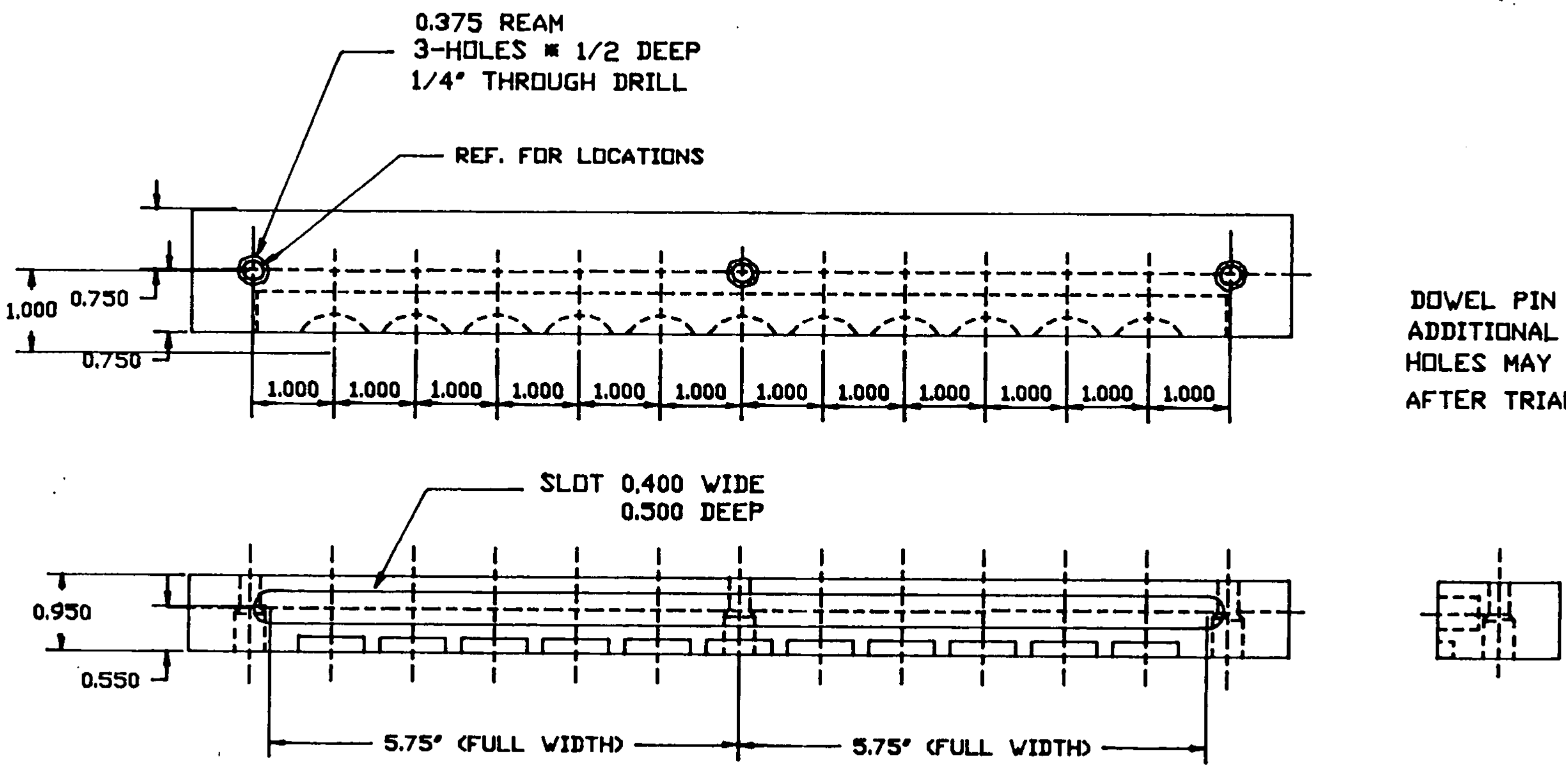
DRAWING: SHUTTLE PLATE BRAIDER GUIDE COMPONENTS	
DRAWN BY:	
DATE:	FILE: M2GUIDE.DWG



EDGE BAR (SHORT)
ALUMINUM

NO. REQ'D: 2

DEPARTMENT OF MECHANICAL ENGINEERING CLEMSON UNIVERSITY CLEMSON, SC
NASA - LANGLEY RESEARCH CENTER CO-OPERATIVE AGREEMENT NCC1-128
DRAWING: SHUTTLE PLATE BRAIDER EDGEBAR (SHORT)
DRAWN BY:
DATE: FILE: EDGEBARS



DOWEL PIN HOLES & ADDITIONAL MOUNTING HOLES MAY BE ADDED AFTER TRIAL ASSEMBLY

EDGE BAR (LONG)

ALUMINUM

NO. REQ'D: 2

DEPARTMENT OF MECHANICAL ENGINEERING CLEMSON UNIVERSITY CLEMSON, SC	
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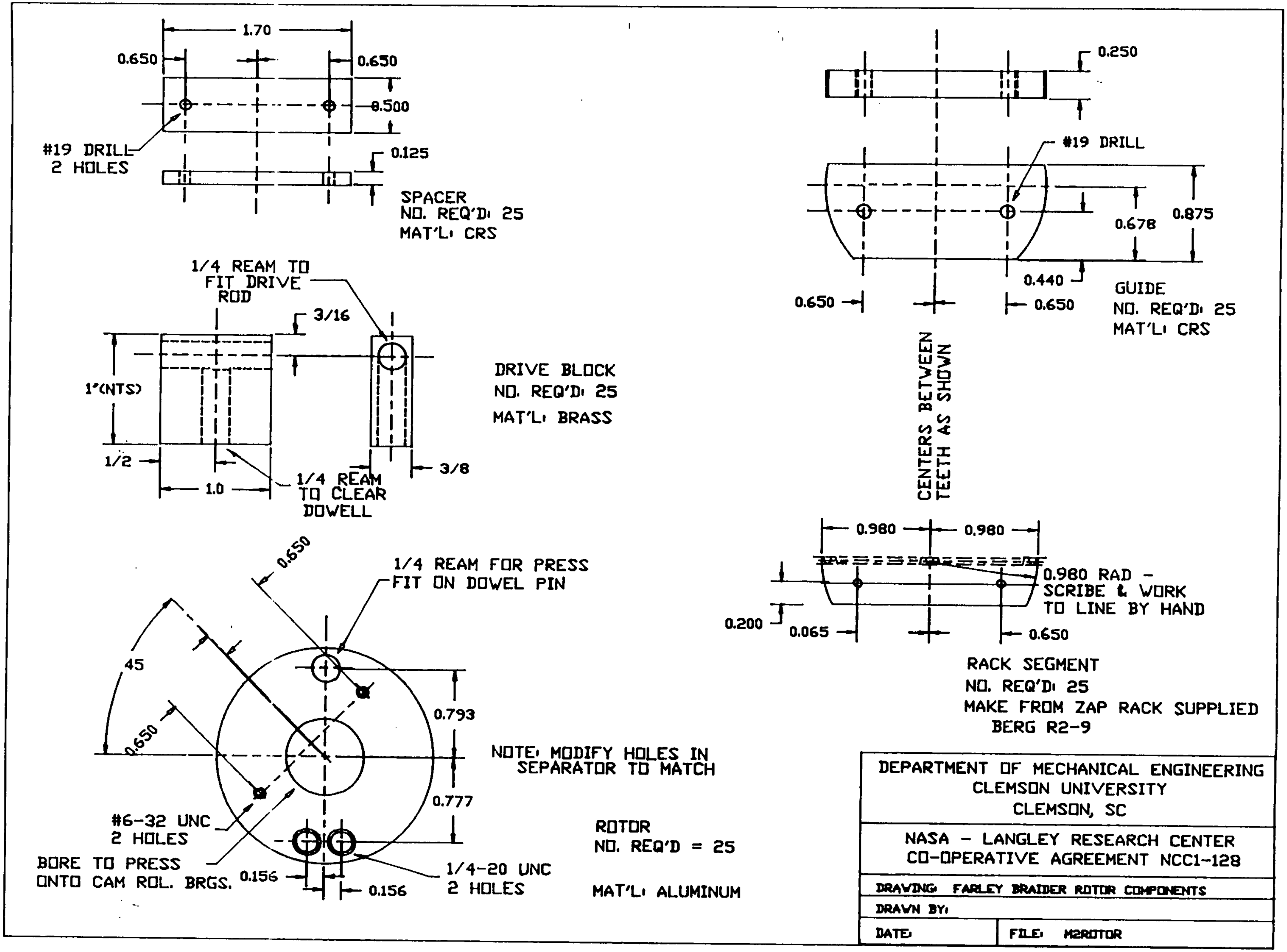
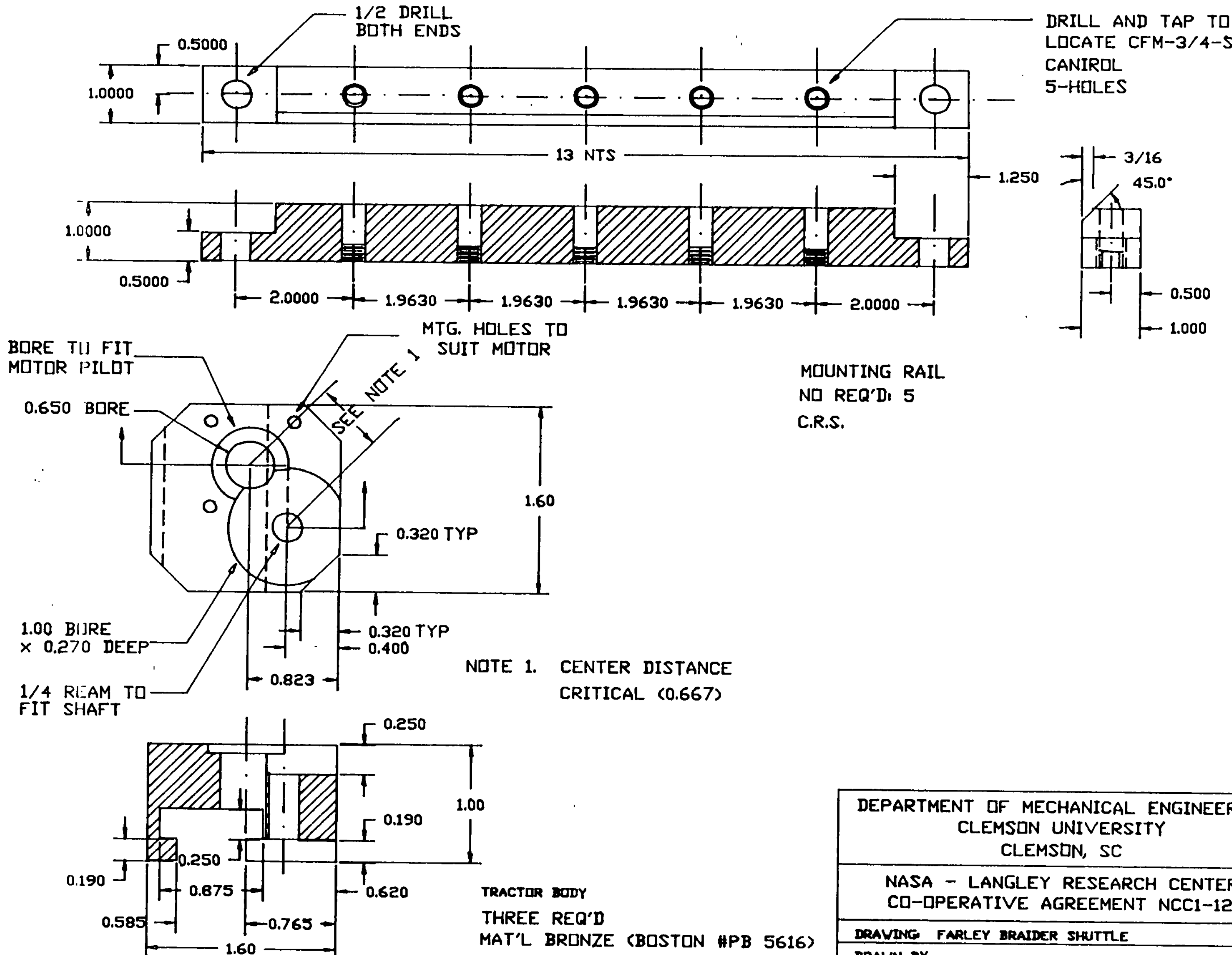
DRAWING: SHUTTLE PLATE BRAIDER EDGEBAR (LONG)	
DRAWN BY:	
DATE:	FILE: EDGEBARL


1.70
0.650
0.650
0.500
#19 DRILL
2 HOLES
0.125
SPACER
NO. REQ'D: 25
MAT'L: CRS
1/4 REAM TO
FIT DRIVE
ROD
3/16
1"(NTS)
1/2
1.0
1/4 REAM
TO CLEAR
DOWELL
3/8
DRIVE BLOCK
NO. REQ'D: 25
MAT'L: BRASS
0.250
#19 DRILL
0.678
0.875
0.440
0.650
0.650
GUIDE
NO. REQ'D: 25
MAT'L: CRS
CENTERS BETWEEN
TEETH AS SHOWN
0.980
0.980
0.980 RAD -
SCRIBE & WORK
TO LINE BY HAND
0.200
0.065
0.650
RACK SEGMENT
NO. REQ'D: 25
MAKE FROM ZAP RACK SUPPLIED
BERG R2-9
0.650
1/4 REAM FOR PRESS
FIT ON DOWEL PIN
45
0.650
0.793
0.777
NOTE: MODIFY HOLES IN
SEPARATOR TO MATCH
#6-32 UNC
2 HOLES
BORE TO PRESS
ONTO CAM ROL. BRGS.
0.156
0.156
1/4-20 UNC
2 HOLES
ROTOR
NO. REQ'D = 25
MAT'L: ALUMINUM
DEPARTMENT OF MECHANICAL ENGINEERING
CLEMSON UNIVERSITY
CLEMSON, SC
NASA - LANGLEY RESEARCH CENTER
CO-OPERATIVE AGREEMENT NCC1-128
DRAWING: FARLEY BRAIDER ROTOR COMPONENTS
DRAWN BY:
DATE:
FILE: M2ROTOR



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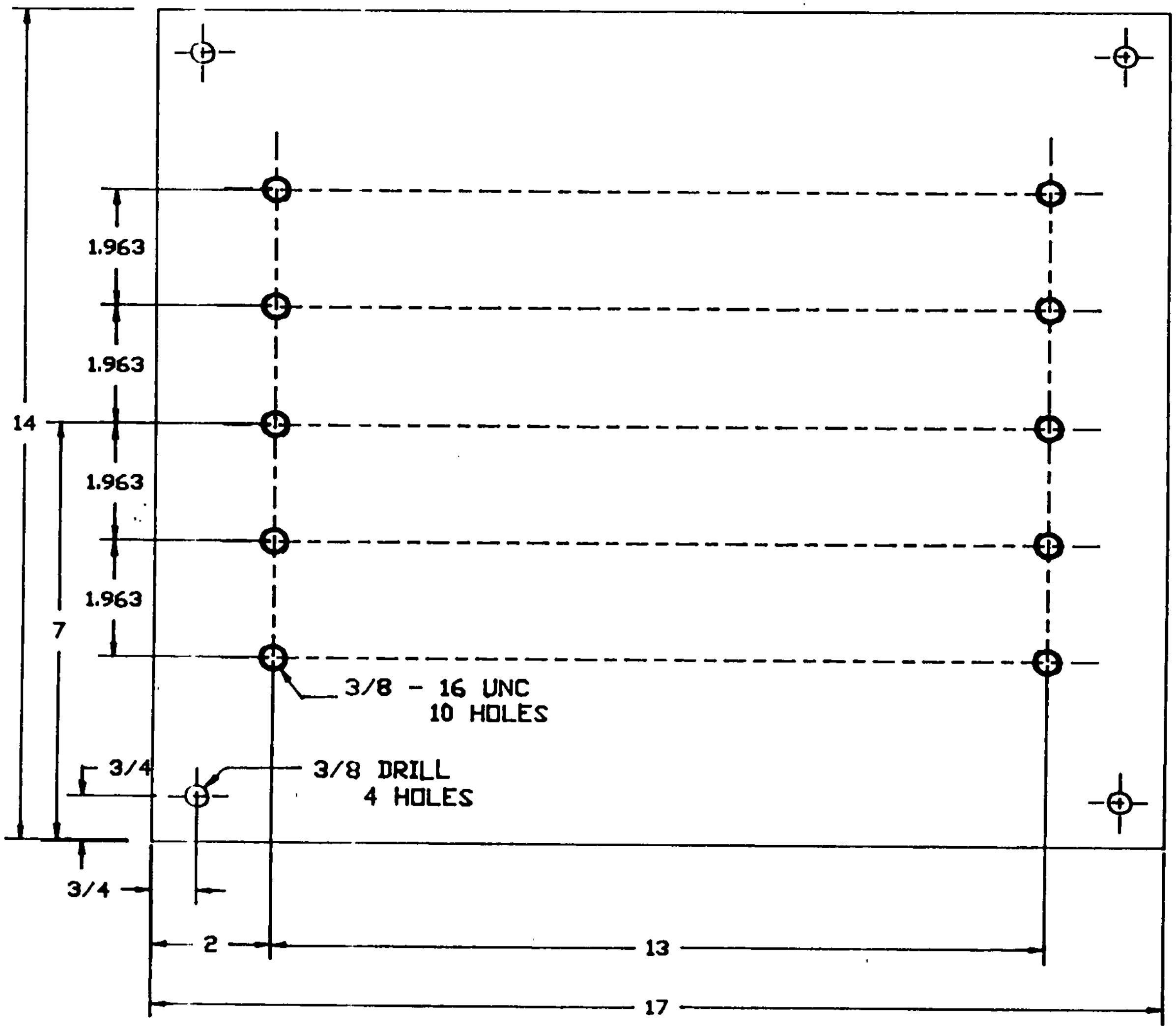
DRAWING: FARLEY BRAIDER SHUTTLE
DRAWN BY:
DATE: FILE: M2SHUTTLE



BASE PLATE
ONE REQ'D
MAT'L: 1/2" ALUM. PLATE

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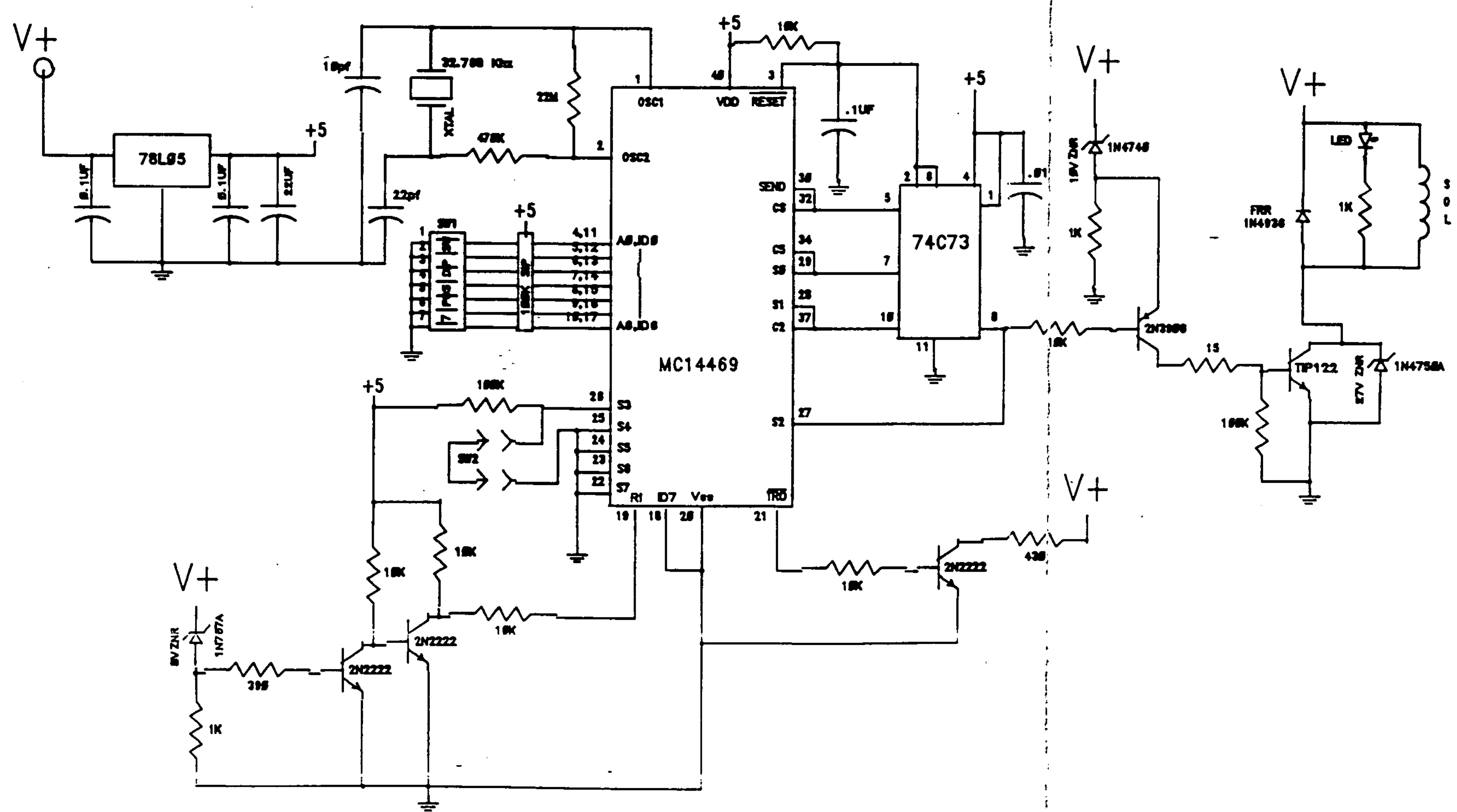
DRAWING: FARLEY BRAIDER BASE PLATE
DRAWN BY:
DATE: FILE: M2PLATE

FOLDOUT FRAME 1

FOLDOUT FRAME 2



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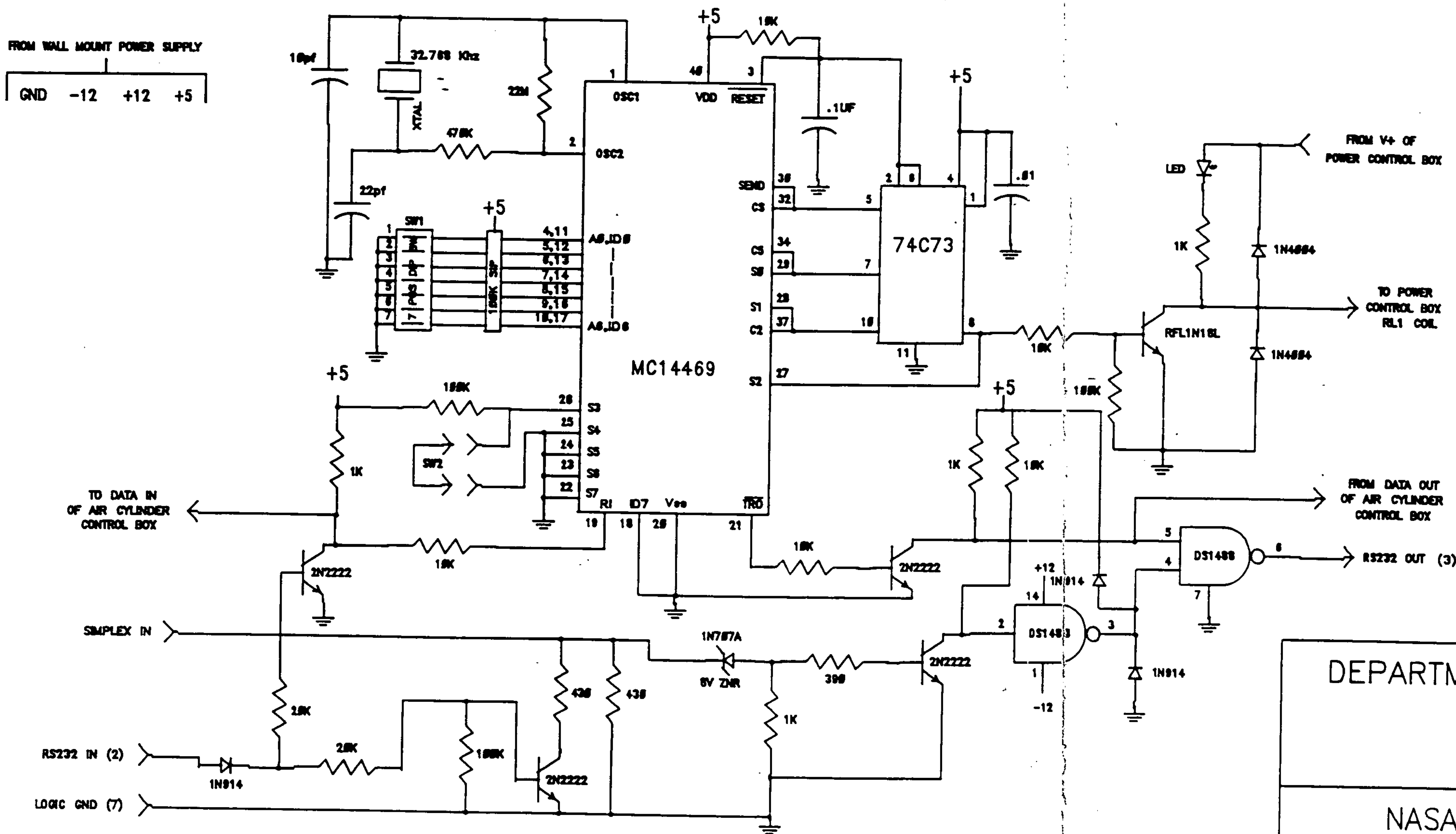
DRAWING: SHUTTLE BRAIDER SHUTTLE CONTROL	
DRAWN BY: DAVID WHITE	
DATE: 7/30/91	FILE: SHUTTLE2.SCH

FOLDOUT FRAME 1.

FOLDOUT FRAME 2.



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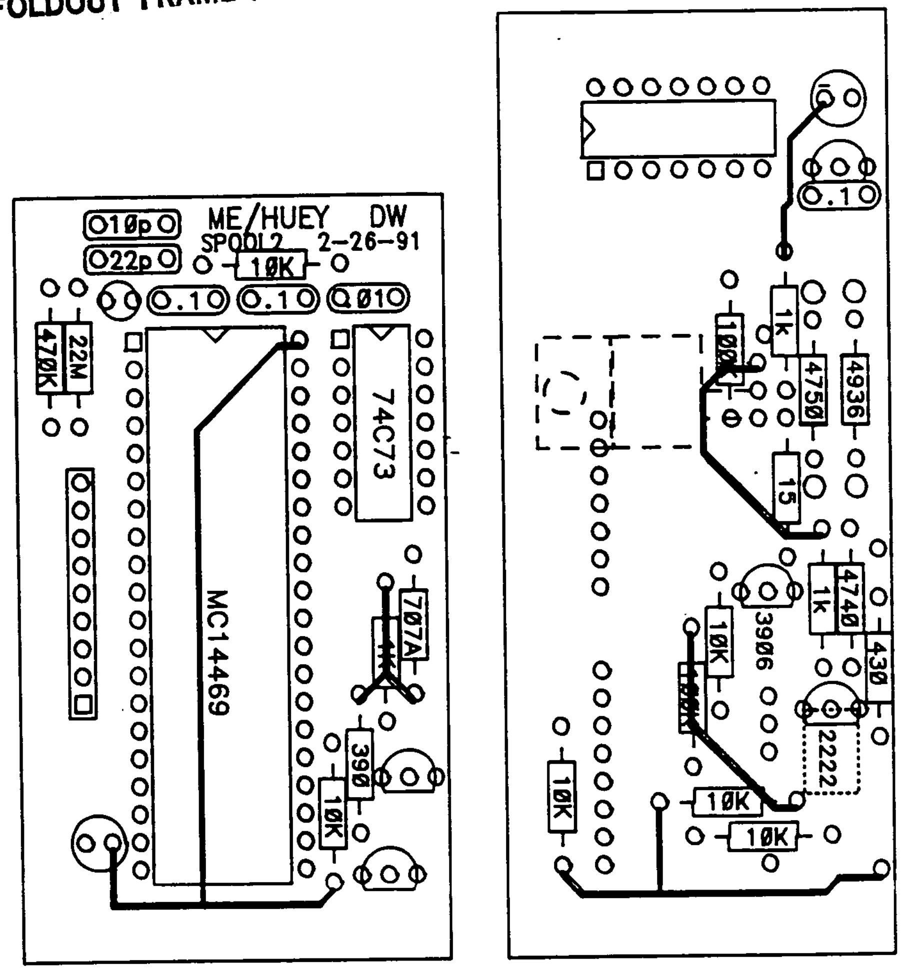
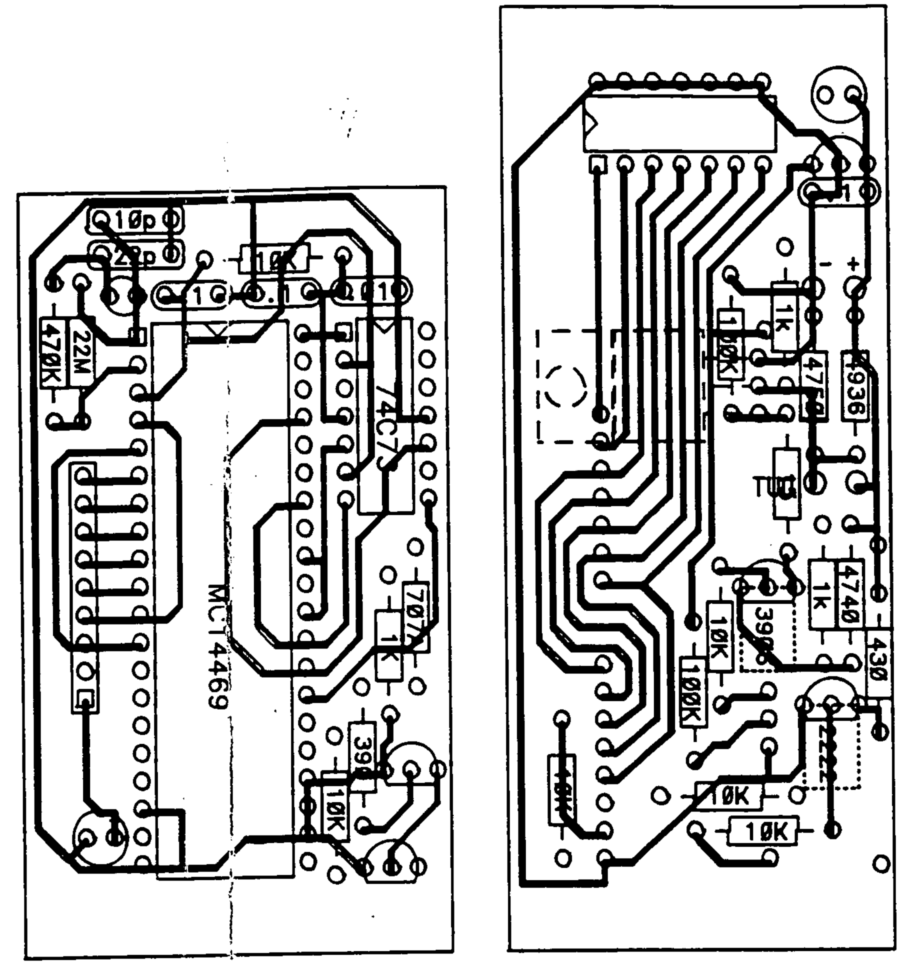
DRAWING: SHUTTLE CONTROLLER COMPUTER INTERFACE	
DRAWN BY: DAVID WHITE	
DATE: 7/30/90	FILE: SHUTLINT.SCH

FOLDOUT FRAME 1

FOLDOUT FRAME 2.



COMPONENT SIDE



SOLDER SIDE

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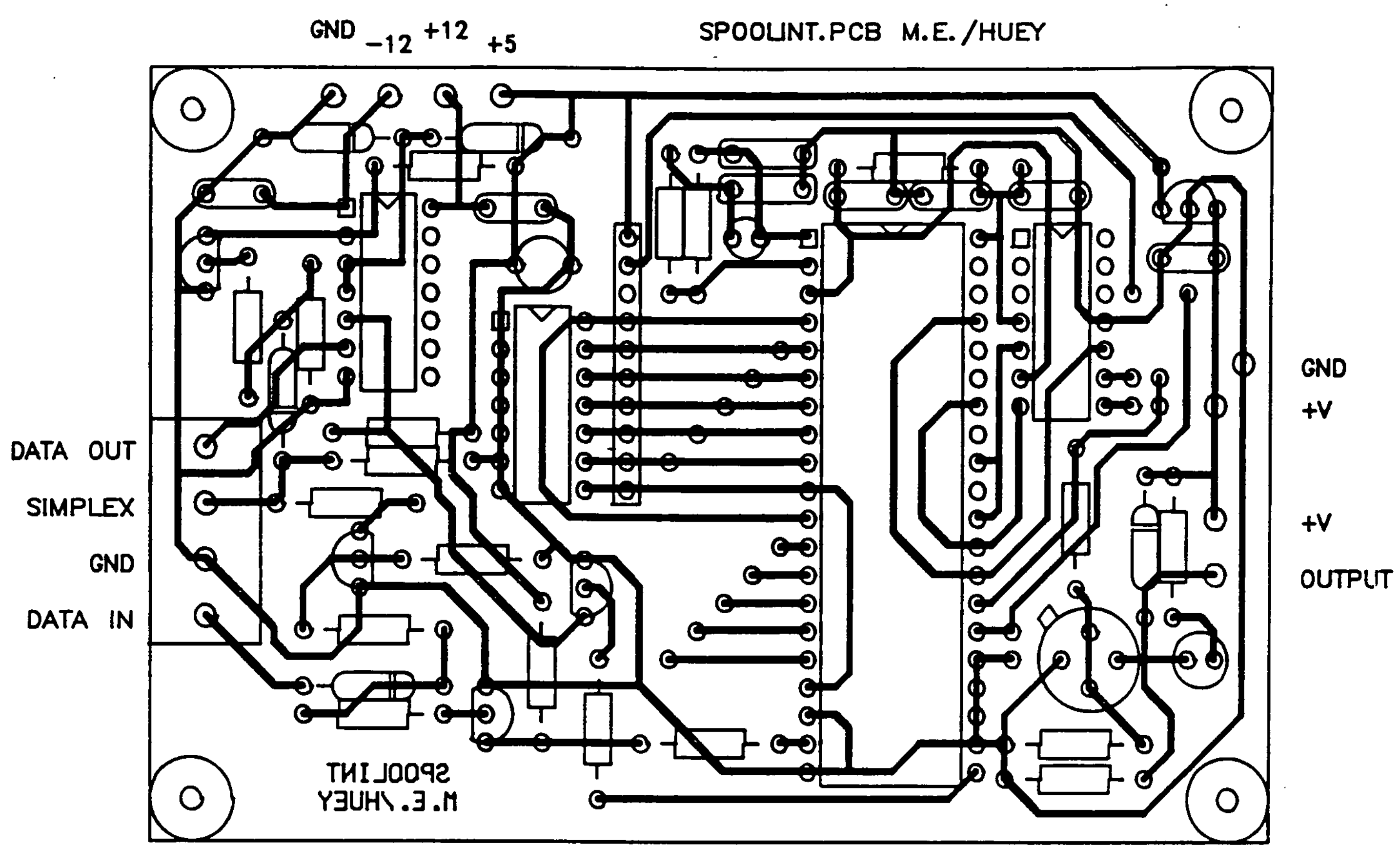
DRAWING: SHUTTLE BRAIDER SHUTTLE CIRCUIT BOARD
DRAWN BY: DAVID WHITE
DATE: 2/26/91   FILE: SHUTTLE2.PCB

FOLDOUT FRAME 1

FOLDOUT FRAME 2



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DRAWING: SHUTTLE BRAIDER INTERFACE CIRCUIT BOARD

DRAWN BY: DAVID WHITE

DATE: 2/12/90	FILE: SHUTLINT.PCB

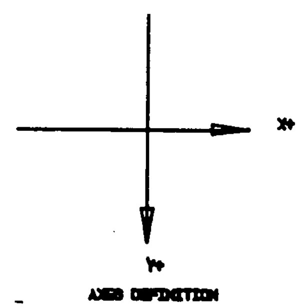
1. FOLDOUT FRAME

2. FOLDOUT FRAME

PORT B - FREQUENCY (DIRECTION, STOP), COLUMN & ROW SELECT

STOP

Fb	Fa	Rc	Rb	Ra	Cc	Cb	Ca
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	1
0	0	0	0	0	0	1	0
0	0	0	0	0	0	1	1
0	0	0	0	0	1	0	0
0	0	0	0	0	1	0	1
0	0	0	0	1	0	0	0
0	0	0	0	1	0	0	1
0	0	0	0	1	0	1	0
0	0	0	0	1	0	1	1
0	0	0	0	1	1	0	0
0	0	0	0	1	1	0	1



START X+, Y+ (RIGHT, DOWN)

Fb	Fa	Rc	Rb	Ra	Cc	Cb	Ca
0	1	0	0	0	0	0	0
0	1	0	0	0	0	0	1
0	1	0	0	0	0	1	0
0	1	0	0	0	0	1	1
0	1	0	0	0	1	0	0
0	1	0	0	0	1	0	1
0	1	0	0	1	0	0	0
0	1	0	0	1	0	0	1
0	1	0	0	1	0	1	0
0	1	0	0	1	0	1	1
0	1	0	0	1	1	0	0
0	1	0	0	1	1	0	1

PORT B PIN CONNECTIONS

PB0 10 COL A
PB1 9 COL B
PB2 8 COL C
PB3 7 ROW A
PB4 6 ROW B
PB5 5 ROW C
PB6 4 FREQ A
PB7 3 FREQ B

START X-, Y- (LEFT, UP)

Fb	Fa	Rc	Rb	Ra	Cc	Cb	Ca
1	0	0	0	0	0	0	0
1	0	0	0	0	0	0	1
1	0	0	0	0	0	1	0
1	0	0	0	0	-0	1	1
1	0	0	0	0	1	0	0
1	0	0	0	0	1	0	1
1	0	0	0	1	0	0	0
1	0	0	0	1	0	0	1
1	0	0	0	1	0	1	0
1	0	0	0	1	0	1	1
1	0	0	0	1	1	0	0
1	0	0	0	1	1	0	1

PORT B ADDRESS = 301H = 769D

SELECT ROW AND COLUMN AND DIRECTION TO START
e.g. FREQ 0,1; ROW 2; COL 1 => 01010001

SELECT DESTINATION ROW AND COLUMN AND STOP
e.g. FREQ 0,0; ROW 2; COL 3 => 00010011

SELECT DIRECTION OF TURNTABLES ON PORT C - BIT 4 (PIN25)

PORT C - ROW DATA FEEDBACK COLUMN SELECT EMITTER $\overline{\text{ENABLE}}$, ROW FEEDBACK $\overline{\text{ENABLE}}$ AND TURNTABLE ROTATE

Ea			T	Efb	Cc	Cb	Ca
X	X	X	0	0	0	0	0
X	X	X	0	0	0	0	1
X	X	X	0	0	0	1	0
X	X	X	0	0	0	1	1
X	X	X	0	0	1	0	0
X	X	X	0	0	1	0	1
X	X	X	0	1	0	0	0
X	X	X	0	1	0	0	1
X	X	X	0	1	0	1	0
X	X	X	0	1	0	1	1
X	X	X	0	1	1	0	0
X	X	X	0	1	1	0	1
0	X	X	X	X	X	X	X

Ea			T	Efb	Cc	Cb	Ca
X	X	X	1	0	0	0	0
X	X	X	1	0	0	0	1
X	X	X	1	0	0	1	0
X	X	X	1	0	0	1	1
X	X	X	1	0	1	0	0
X	X	X	1	0	1	0	1
X	X	X	1	1	0	0	0
X	X	X	1	1	0	0	1
X	X	X	1	1	0	1	0
X	X	X	1	1	0	1	1
X	X	X	1	1	1	0	0
X	X	X	1	1	1	0	1

COLUMN SELECT FOR ROW FEEDBACK

Ca - PC0 - PIN 29
Cb - PC1 - PIN 28
Cc - PC2 - PIN 27

ENABLE FEEDBACK

Efb - PC3 - PIN 26

TABLE ROTATE

T - PC4 - PIN 25

ENABLE LED EMITTERS

Ea - PC7 - PIN 22

USE MASKING TO CHANGE COLUMN SELECT WHILE MAINTAINING OTHER BIT VALUES.

e.g. TO CHANGE PORT C BIT PATTERN FROM 00000010 TO 00000011.

AND THE FIRST WORD (00000010) WITH 11111000 AND OR IT WITH 00000011.

'AND' ALL BITS NOT TO BE CHANGED WITH '1'.
AND 'OR' THE RESULT WITH THE BITS TO BE CHANGED

PORT A ROW FEEDBACK DATA (INPUT)

PORT C BITS 0-2

NC	NC	R5	R4	R3	R2	R1	R0	Cc	Cb	Ca
X	X	1	1	1	1	1	1	0	0	0
X	X	1	1	1	0	1	1	0	0	1
X	X	1	1	1	0	1	1	0	1	0
X	X	1	1	1	0	1	1	0	1	1
X	X	1	1	1	1	1	1	1	0	0
X	X	1	1	1	1	1	1	1	0	1

PORT A PIN CONNECTIONS

PA0 - ROW 0 - PIN 37
PA1 - ROW 1 - PIN 36
PA2 - ROW 2 - PIN 35
PA3 - ROW 3 - PIN 34
PA4 - ROW 4 - PIN 33
PA5 - ROW 5 - PIN 32
PA6 - NC - PIN 31
PA7 - NC - PIN30

INITIAL CONDITIONS INDICATE THAT
ROW 2 IS OCCUPIED IN COLUMNS 1, 2 AND 3
START MOTION IN COLUMNS 1, 2 AND 3
SUCH THAT CARRIERS LOCATED IN ROW2-COL1 AND ROW2-COL3
MOVE IN THE +Y DIRECTION, AND CARRIER LOCATED IN ROW2-COL2
MOVES IN THE -Y DIRECTION

X	X	1	1	1	1	1	1	0	0	0
X	X	1	1	0	1	1	1	0	0	1
X	X	1	1	1	1	0	1	0	1	0
X	X	1	0	1	1	1	1	0	1	1
X	X	1	1	1	1	1	1	1	0	0
X	X	1	1	1	1	1	1	1	0	1

ROTATE TABLE SUCH THAT NEXT MOTION IS IN +/- X DIRECTION
START MOTION IN THE +X DIRECTION FOR CARRIERS LOCATED
IN ROW3-COL2 AND ROW1-COL3, AND
START MOTION FOR CARRIER LOCATED IN ROW4-COL1 IN -X DIRECTION

X	X	1	1	1	1	1	1	0	0	0
X	X	1	0	1	1	1	1	0	0	1
X	X	1	1	0	1	1	1	0	1	0
X	X	1	1	1	1	0	1	0	1	1
X	X	1	1	1	1	1	1	1	0	0
X	X	1	1	1	1	1	1	1	0	1

ROTATE TABLE SUCH THAT NEXT MOTION IS IN THE +/- Y DIRECTION
START MOTION IN THE -Y DIRECTION FOR THE CARRIERS LOCATED
IN ROW4-COL1 AND ROW3-COL2, AND
START MOTION FOR CARRIER LOCATED IN ROW1-COL3 IN +Y DIRECTION

X	X	1	1	1	1	1	1	0	0	0
X	X	1	1	0	1	1	1	0	0	1
X	X	1	1	1	1	0	1	0	1	0
X	X	1	0	1	1	1	1	0	1	1
X	X	1	1	1	1	1	1	1	0	0
X	X	1	1	1	1	1	1	1	0	1

REPEAT

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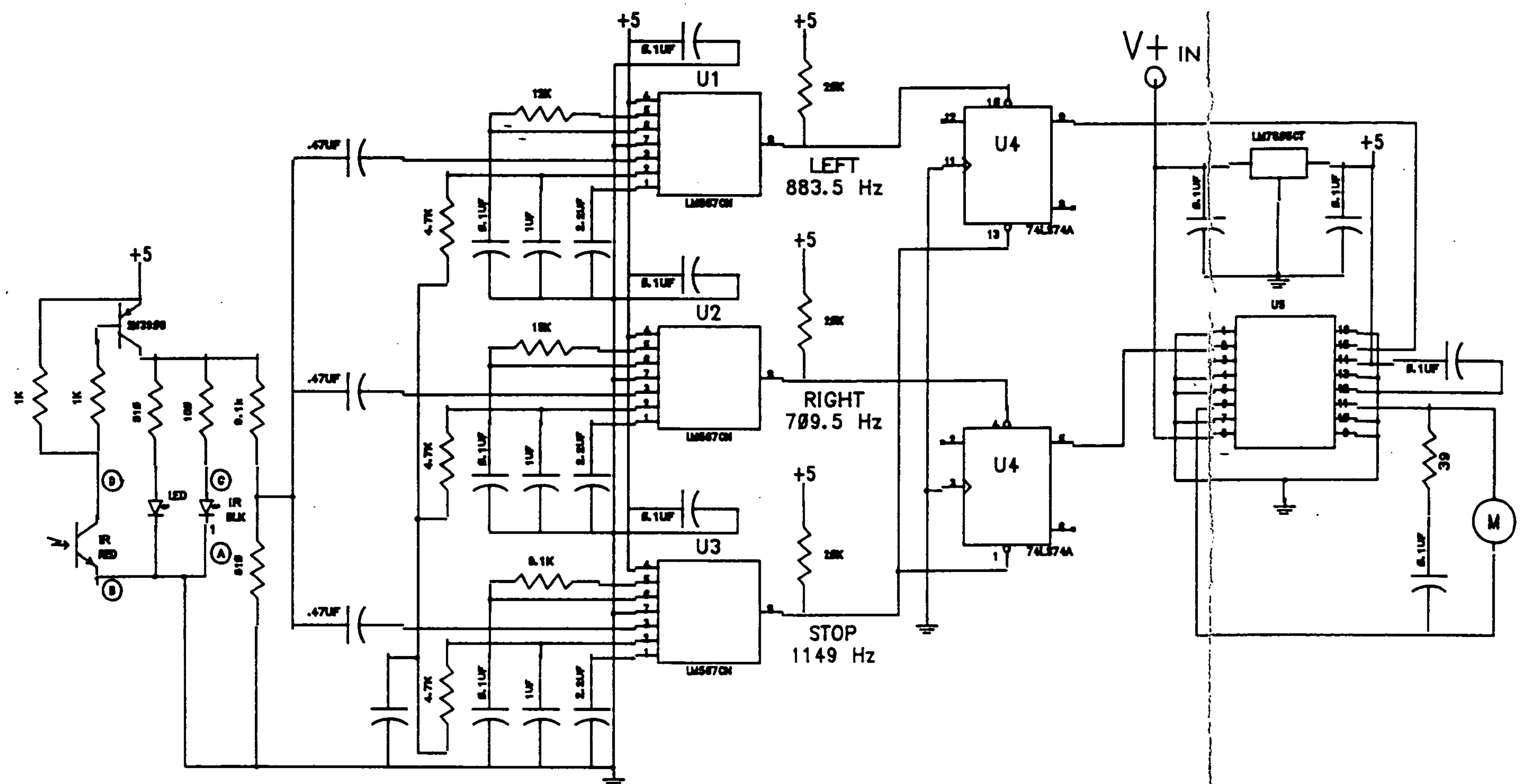
DRAWING: PORT CONNECTIONS AND FUNCTIONS
DRAWN BY: W.L. WILLIS
DATE: 12/10/90 FILE: FARLEY1.PRT

1.
FOLDOUT FRAME

2.
FOLDOUT FRAME



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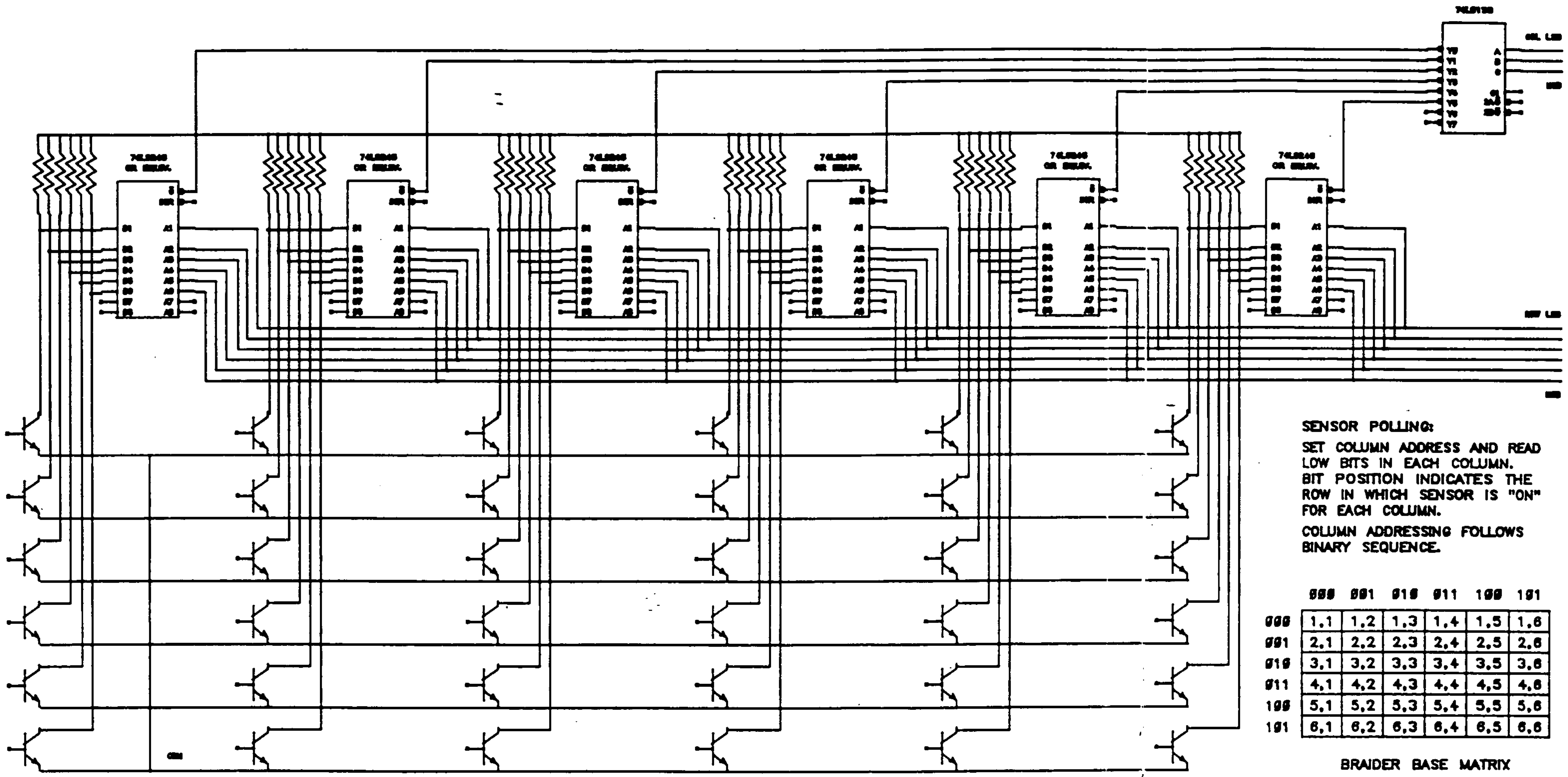
DRAWING: FARLEY SHUTTLE CONTROLLER SCHEMATIC

DRAWN BY: DAVID WHITE

DATE: 3/29/91 | FILE: FARLEYSB.SCH

FOLDOUT FRAME /

FOLDOUT FRAME 2



SENSOR POLLING:

SET COLUMN ADDRESS AND READ LOW BITS IN EACH COLUMN. BIT POSITION INDICATES THE ROW IN WHICH SENSOR IS "ON" FOR EACH COLUMN.

COLUMN ADDRESSING FOLLOWS BINARY SEQUENCE.

	000	001	010	011	100	101
000	1,1	1,2	1,3	1,4	1,5	1,6
001	2,1	2,2	2,3	2,4	2,5	2,6
010	3,1	3,2	3,3	3,4	3,5	3,6
011	4,1	4,2	4,3	4,4	4,5	4,6
100	5,1	5,2	5,3	5,4	5,5	5,6
101	6,1	6,2	6,3	6,4	6,5	6,6

BRAIDER BASE MATRIX

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DRAWING: FARLEY BRAIDER FEEDBACK DETECTOR

DRAWN BY: W.L. WILLIS

DATE: 8/30/90 | FILE: FARLEYFB.SCH

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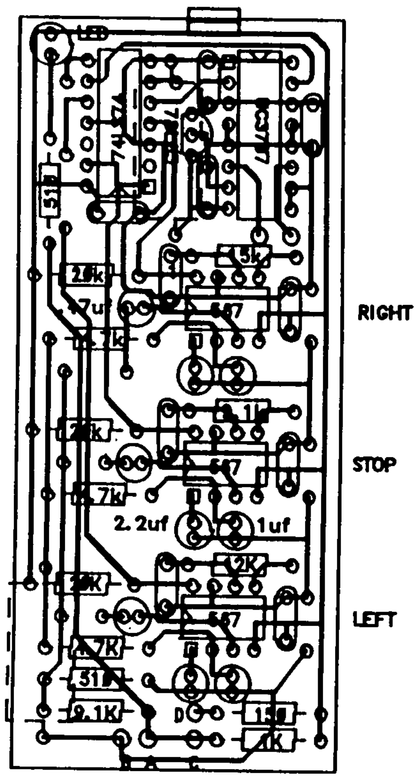
OF POOR QUALITY



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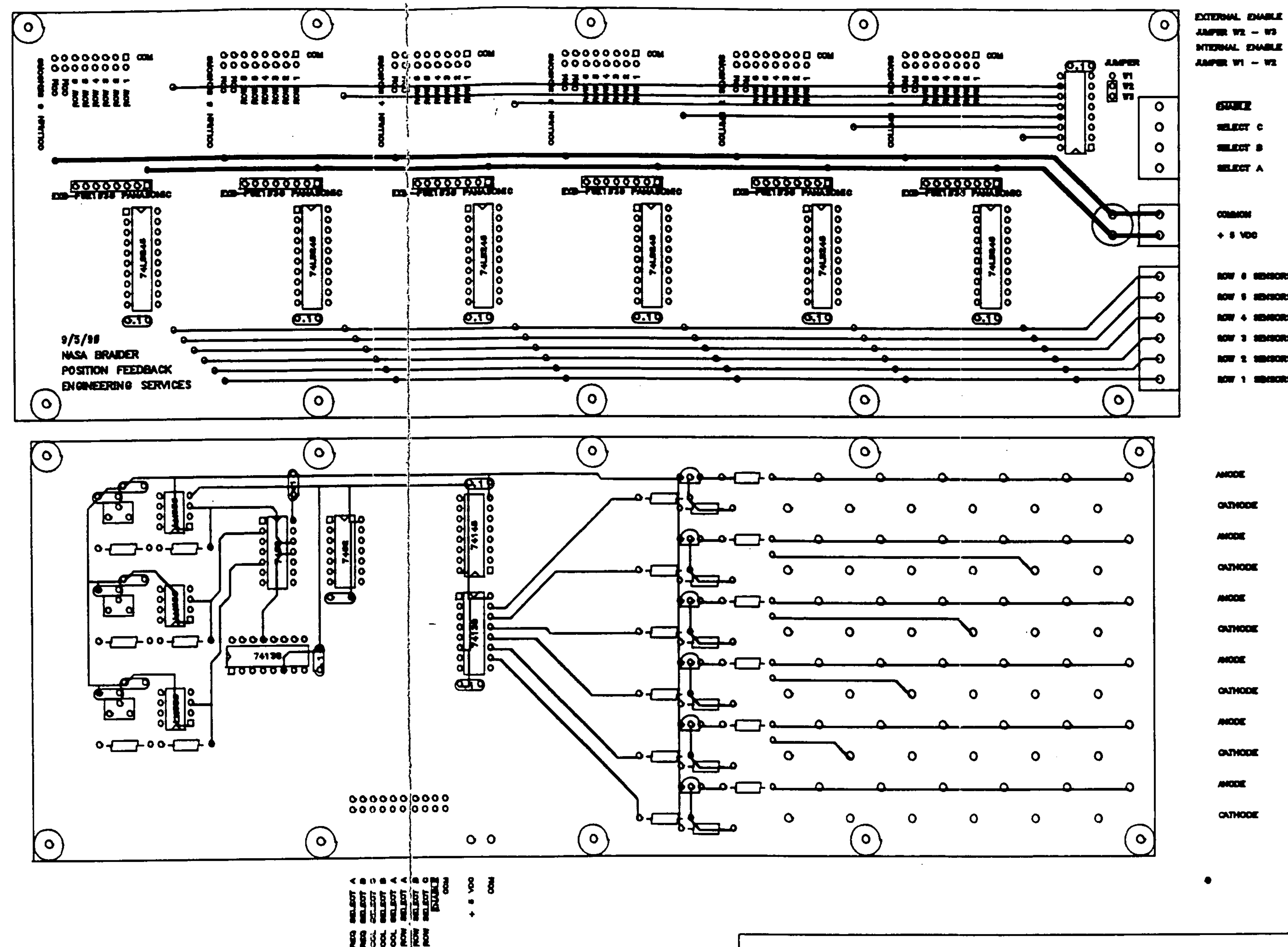
DRAWING: FARLEY SHUTTLE BOARD	
DRAWN BY: DAVID WHITE	
DATE: 11/15/90	FILE: FARLEYSB.PCB

1.

FOLDOUT FRAME

2.

FOLDOUT FRAME



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DRAWING: EMITTER DRIVER; FEEDBACK DETECTOR PCB'S
DRAWN BY: W.L. WILLIS
DATE: 11/19/90 | FILE: FARLEY3B.PCB

BOARD LAYER 1

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ORIGINAL PAGE IS
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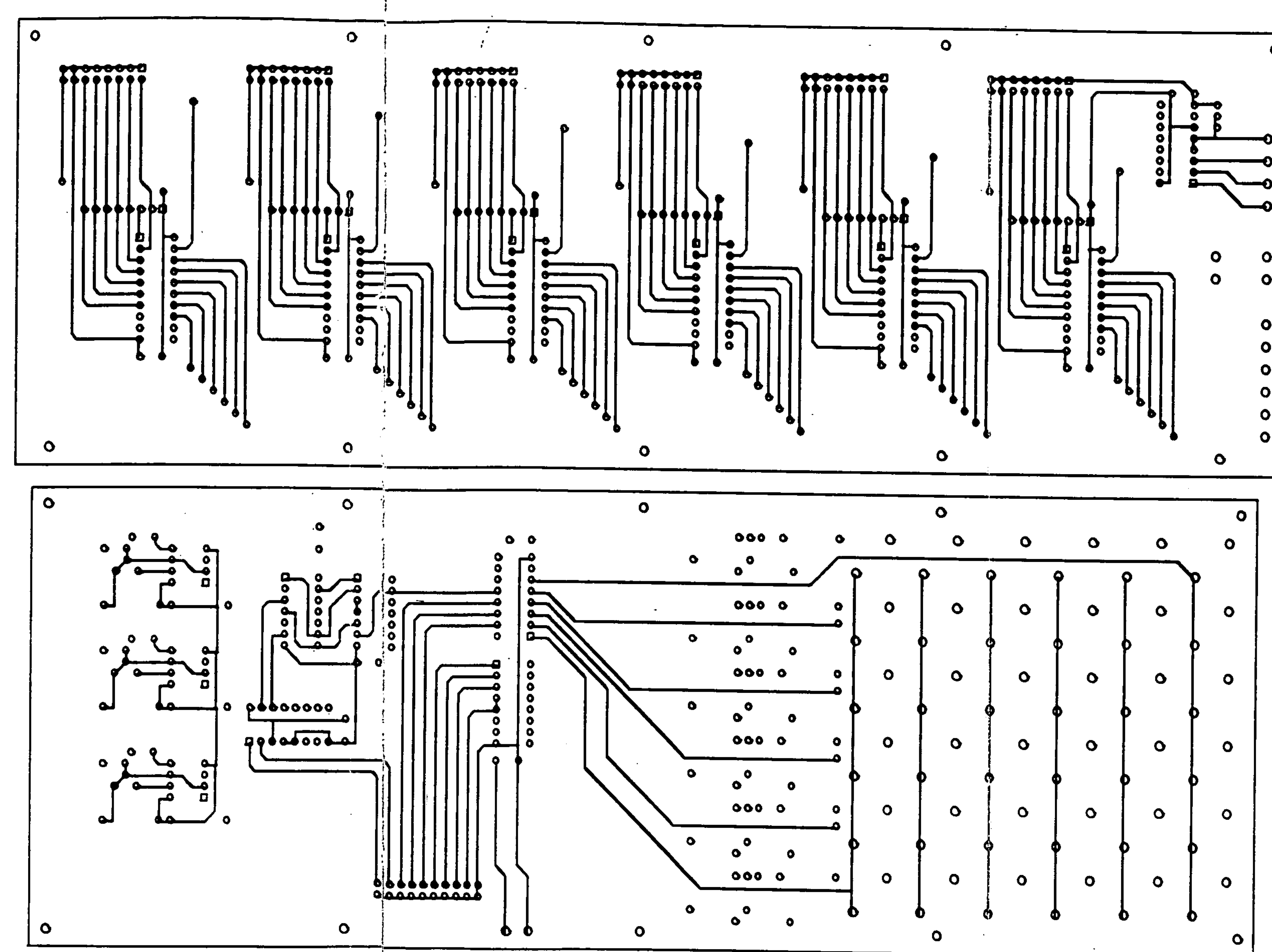
FOLDOUT FRAME 1.

FOLDOUT FRAME 2.



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DRAWING: EMITTER DRIVER; FEEDBACK DETECTOR PCB'S
DRAWN BY: W.L. WILLIS
DATE: 11/19/90 | FILE: FARLEY3B.PCB

BOARD LAYER 2

Appendix F:

Additional Photographs

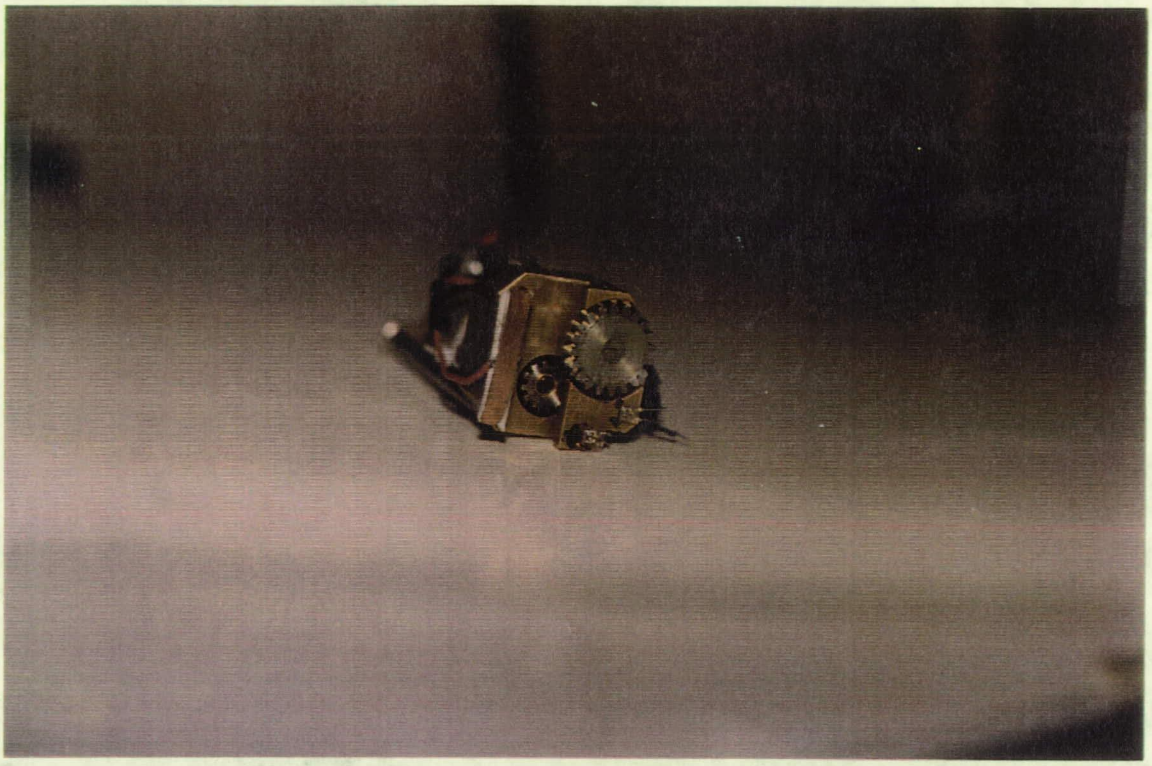

Figure F.1: The Modified Farley Braider Yarn-Carrying Tractor (Bottom View).

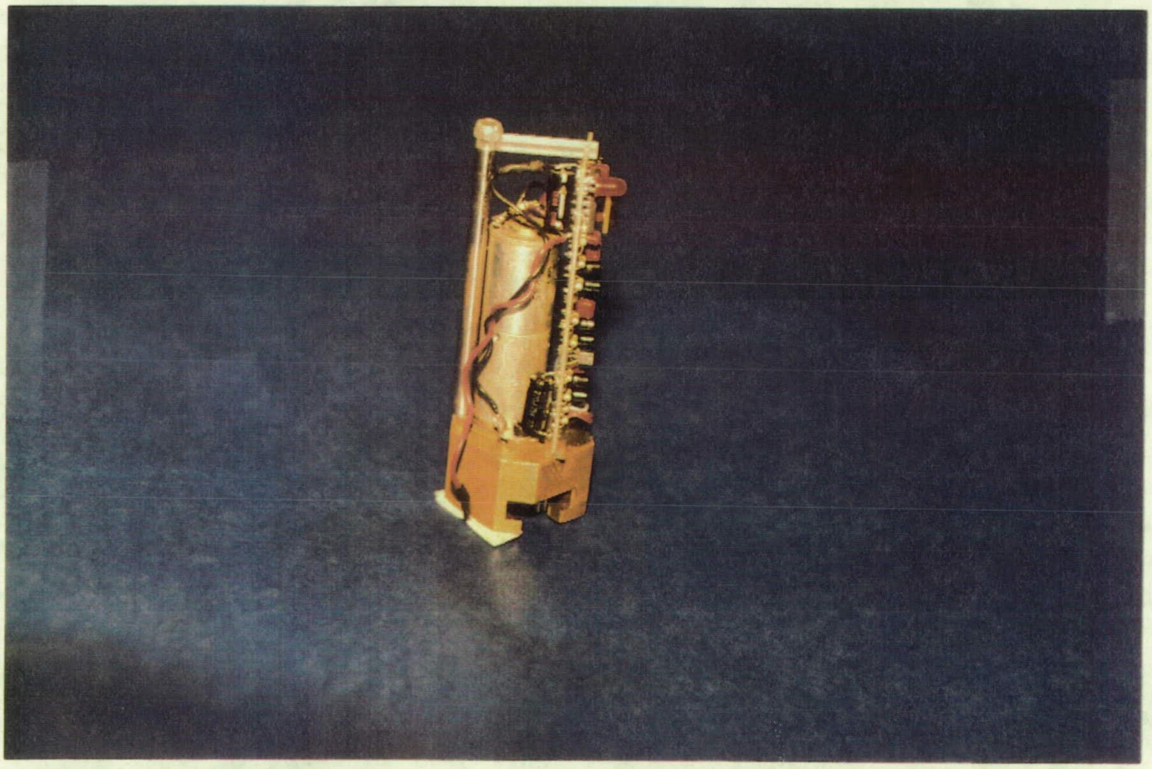

Figure F.2: Yarn-Carying Tractor (Side View).

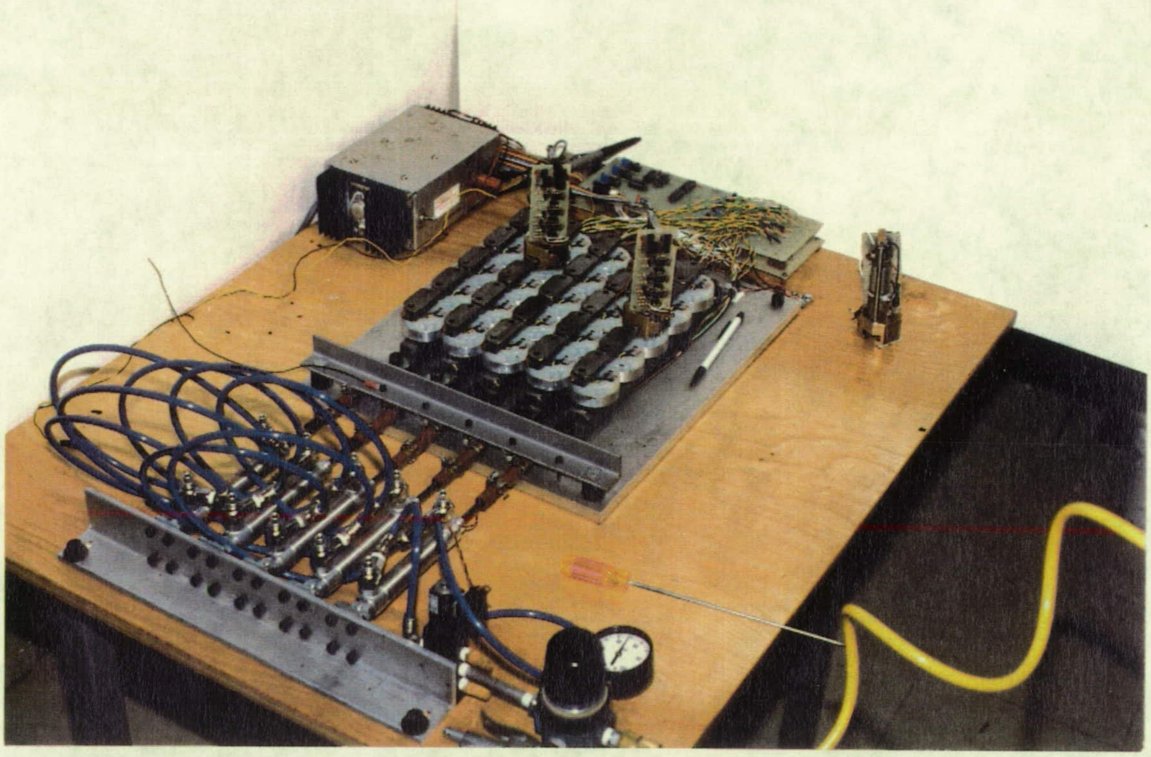

Figure F.3: The Modified Farley Braider Assembled

Braiding Surface, with Tractors.

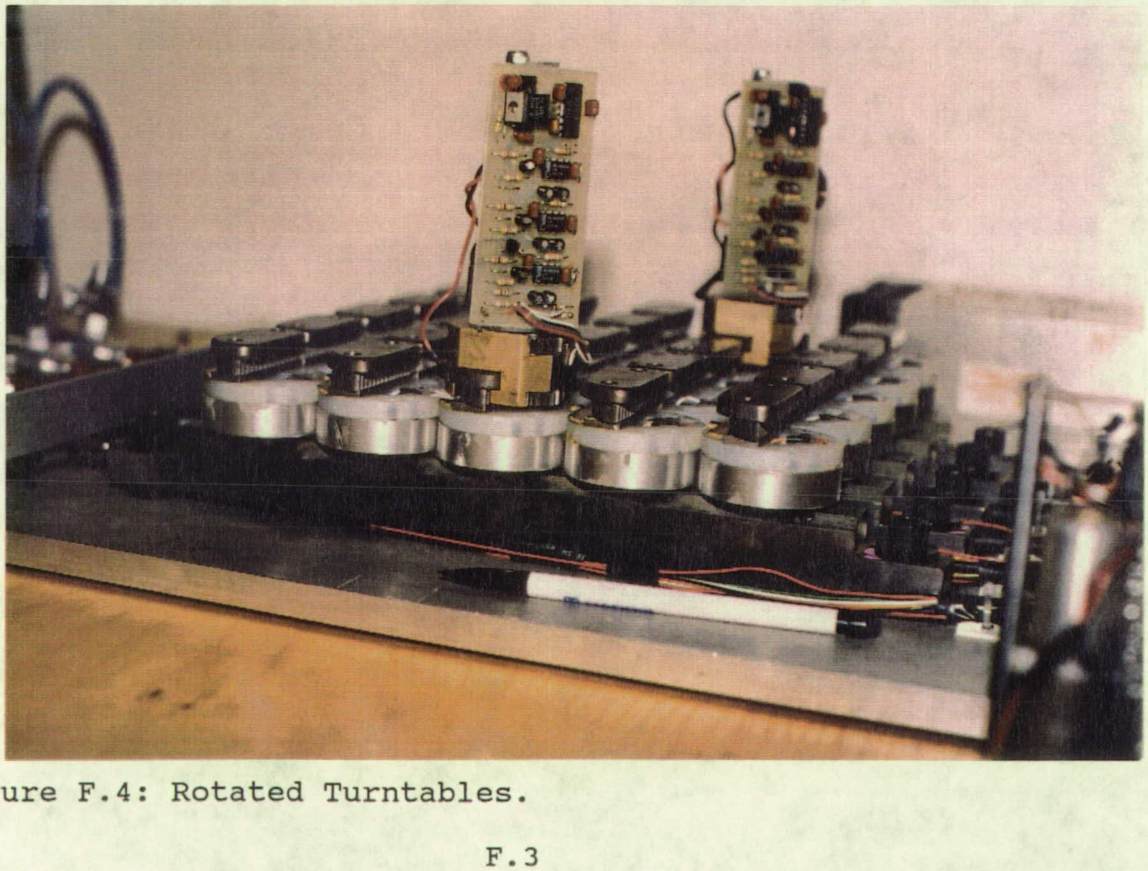

Figure F.4: Rotated Turntables.

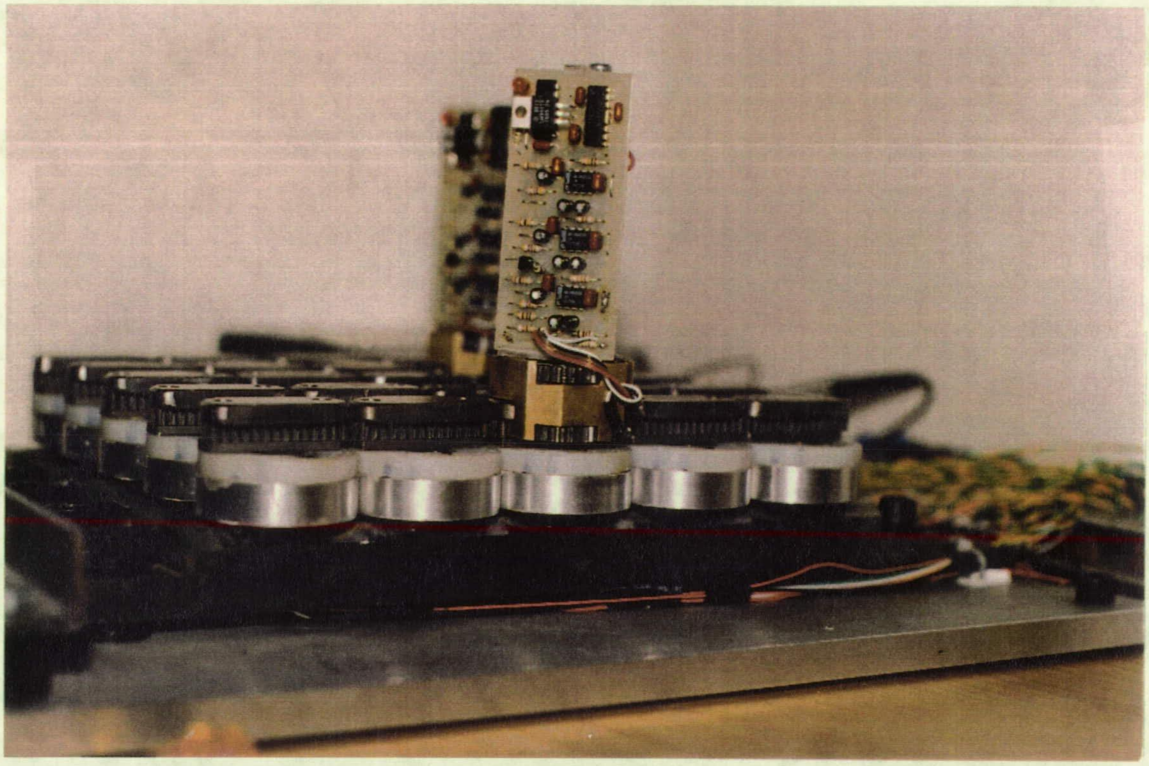

Figure F.5: Close-Up of Turntables and Rack.

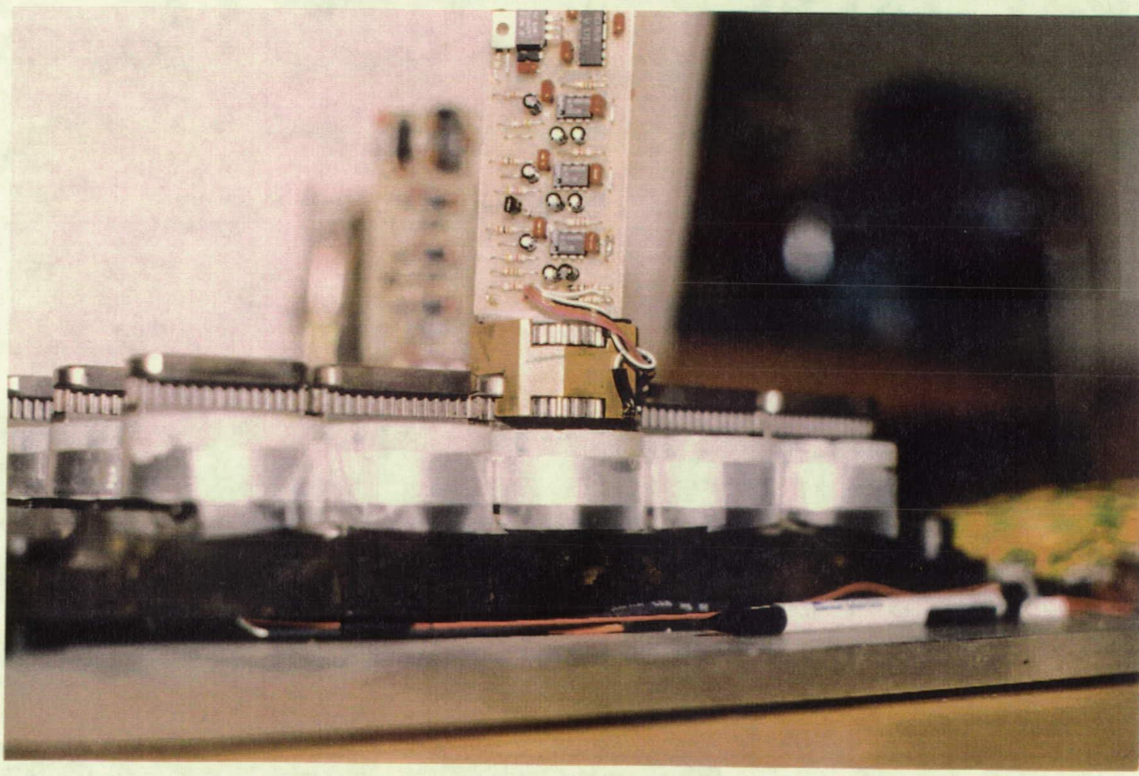

Figure F.6: Additional Close-Up.

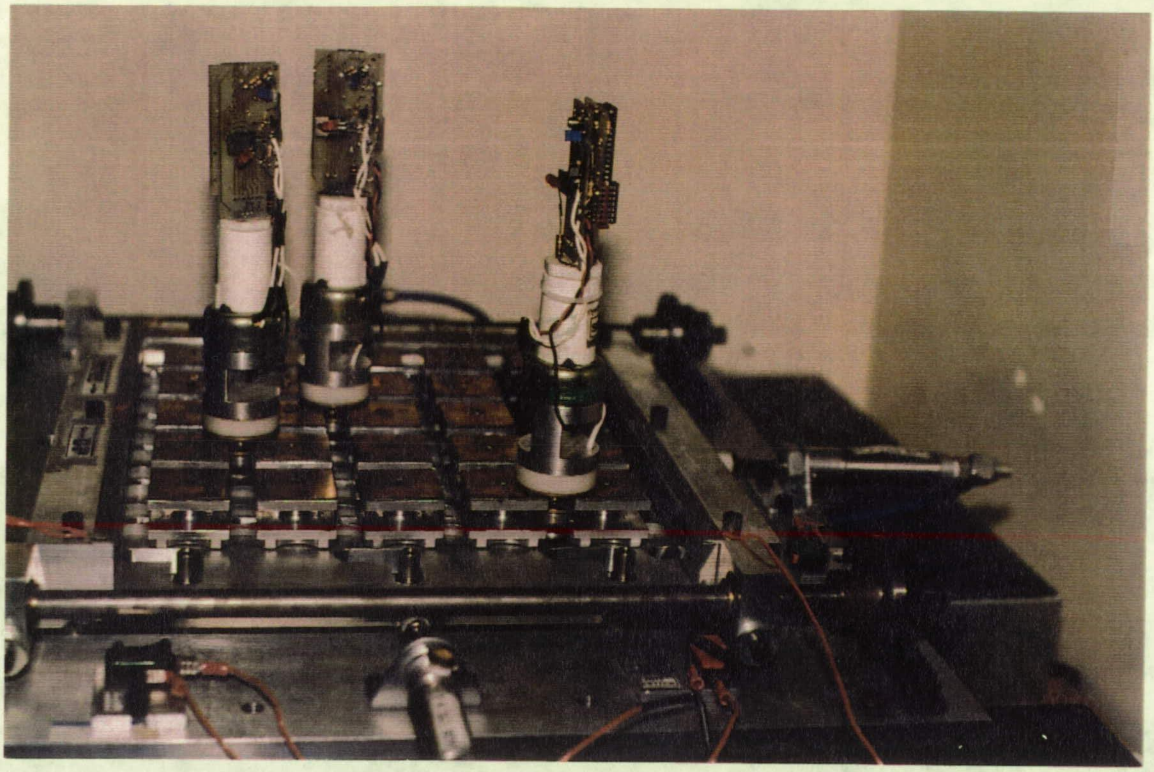

Figure F.7: Shuttle Plate Braider, with Shuttles
Disengaged, Forward Position.

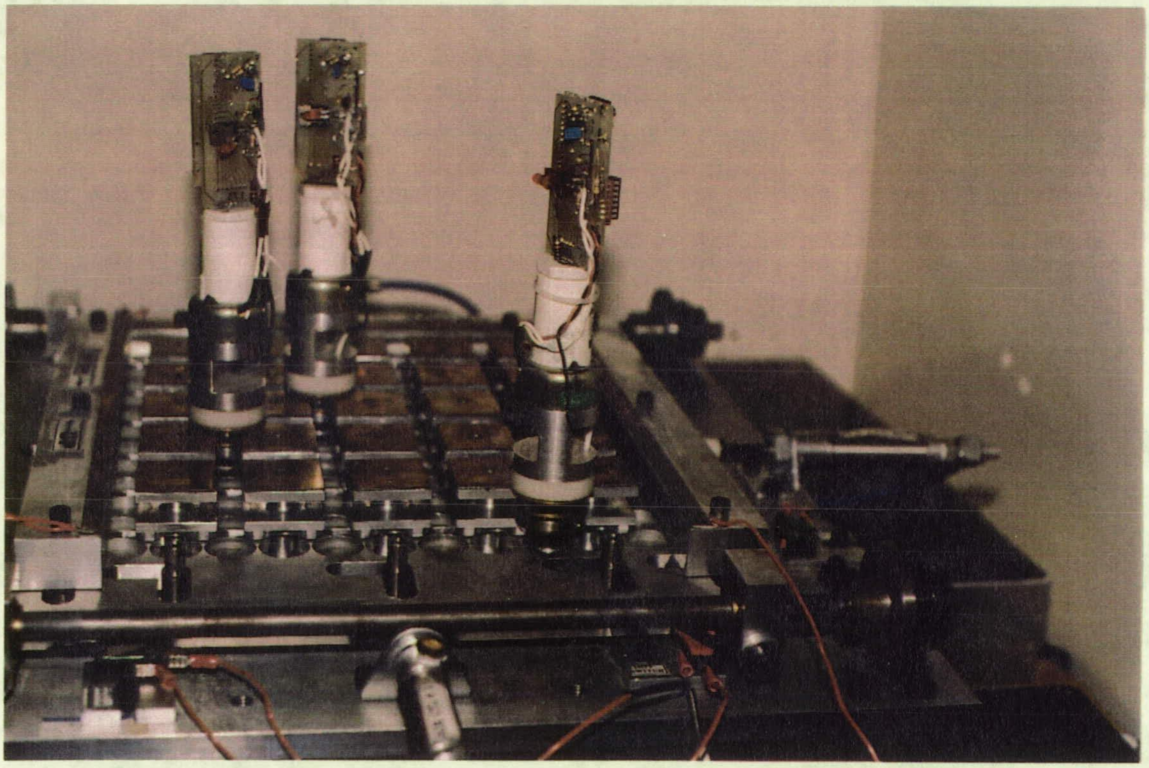

Figure F.8: Shuttle (Right) Engaged, Home Position.

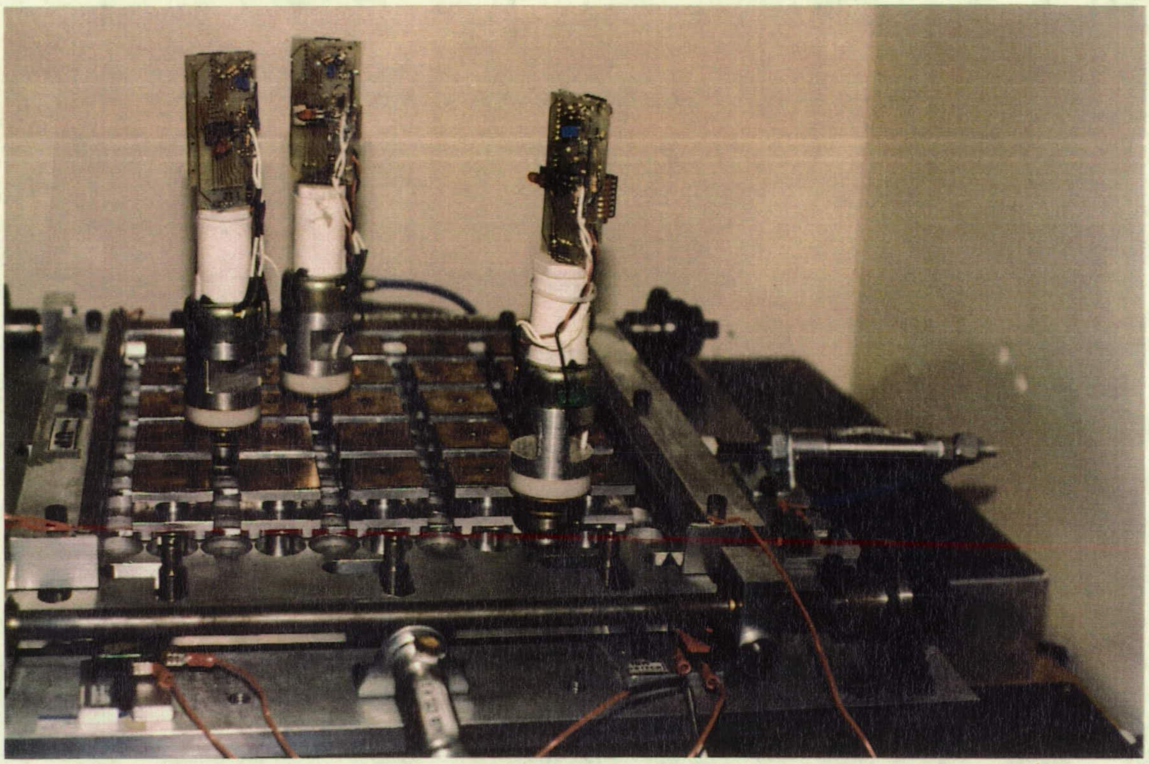

Figure F.9: Shuttles Disengaged, Home Position.

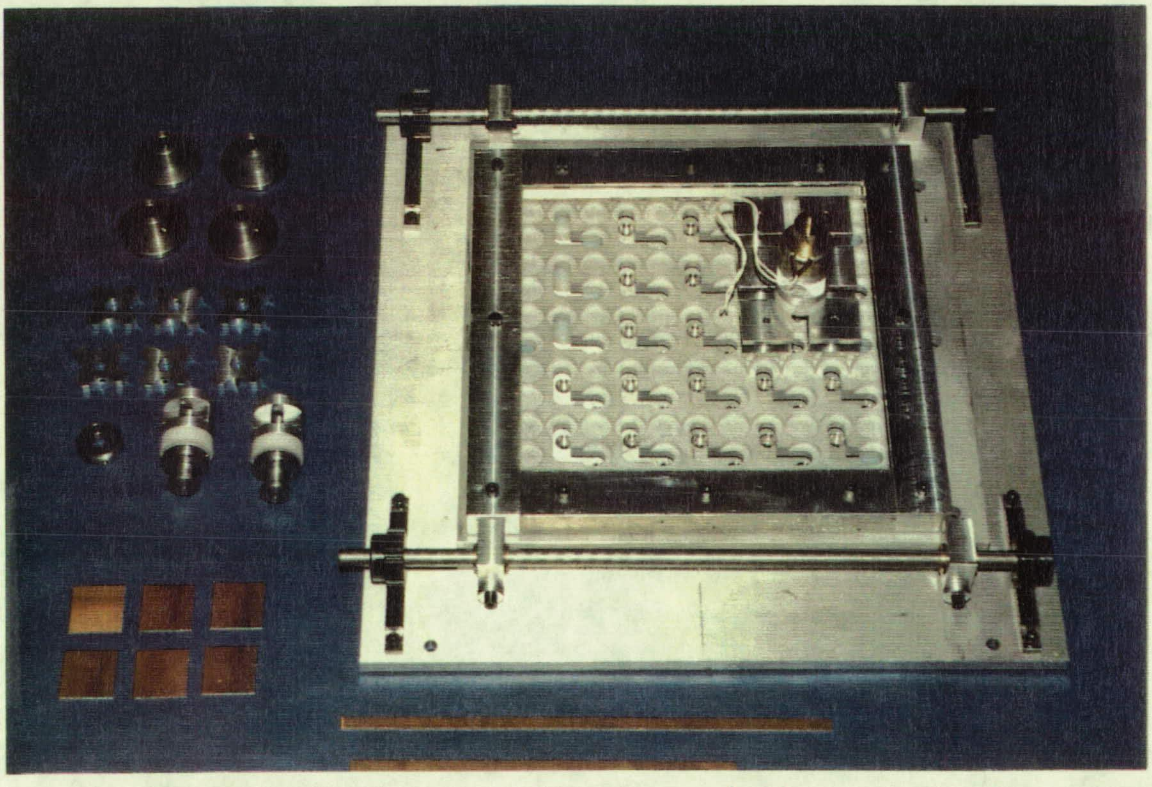

Figure F.10: Shuttle Plate Braider, Partially Assembled Braiding Surface, and Components.

Appendix G:

Braiding Speed Study

The relative braiding speed of the modified Farley braider as compared to the shuttle plate braider was approximately quantified at a cursory level. Having no particular test patterns to use for comparisons, tables of random moves were used instead. More realistic comparisons can be made when move tables for practical braid patterns become available. The tables used varied in length from 56 to 200 braiding cycles for each machine. Each action in the braiding sequence was analyzed to determine the time required for execution. Estimates of maximum, minimum and most likely times were made. Statistical methods similar to those used in PERT (Program Evaluation and Review Technique) were then used to calculate t_e, "expected time to complete."

In this study, the assumption is made that the estimated time follows a Beta distribution. Hence, the variance is calculated as:

$$V(t) = ((t_p - t_o)/6)^2$$

and $$t_e = (t_o + 4t_m + t_p)/6$$

where t_o is the optimistic time estimate, t_m is the most likely time estimate, and t_p is the pessimistic time estimate.

Three different conditions were also assumed. The first

was to assume that the two braiders exist as currently configured. In the other two cases, it is assume that speed enhancing changes have been made to the shuttle plate braider. The first of these is to eliminate the "half-step" motion of the shuttle, and increase its incremental motion to a full-step with each motion. Thus the number of steps is cut in half. This is a reasonable assumption, since a redesign has already been conceived that would allow this improvement. Another additional improvement would be a change of the slots in the shuttle plate to a square shape to eliminate occasional wasted moves of the plate.

The results of the study are shown in Tables G.1, G.2, and G.3. In each case it should be noted that the modified Farley braider is faster than the shuttle plate braider, although the envisioned design modifications have a significant effect on the speed of the shuttle plate braider. As the individual path lengths of any given set of moves are shortened, the advantages of the modified Farley braider diminishes. On the other hand, the modified Farley braider would gain in advantage for patterns consisting primarily of longer, straight yarn displacements.

The computer algorithm which was used to achieve the comparison is given as figure G.4. The computer program used to calculate the comparisons of the current conditions is attached.

Table G.1: Cycle Time Comparison, Present Design

No. of Moves	No. of Spools	t_c for Sh. Pl. Br.	t_c for Far. Br.
56(Farley)/112	3	538.18	182.97
100/200	4	1004.58	344.42
150/300	4	1521.28	494.88
200/400	5	2015.82	664.48

Table G.2: Cycle Time Comparison, Full-step Shuttle

No. of Moves	No. of Spools	t_c for Sh. Pl. Br.	t_c for Far. Br.
56	3	241.38	182.97
100	4	474.58	344.42
150	4	726.28	494.88
200	5	955.82	664.48

* (CU BR = Shuttle Plate Braider)
(FAR BR = Modified Farley Braider)

No. of Moves	No. of Spools	t_c for Sh. Pl. Br.	t_c for Far. Br.
56	3	223.65	182.97
100	4	416.95	344.42
150	4	639.83	494.88
200	5	840.55	664.48

Table G.3 Cycle Time Comparison, Shuttle Plate Slot Change as Well as Full-step Shuttle

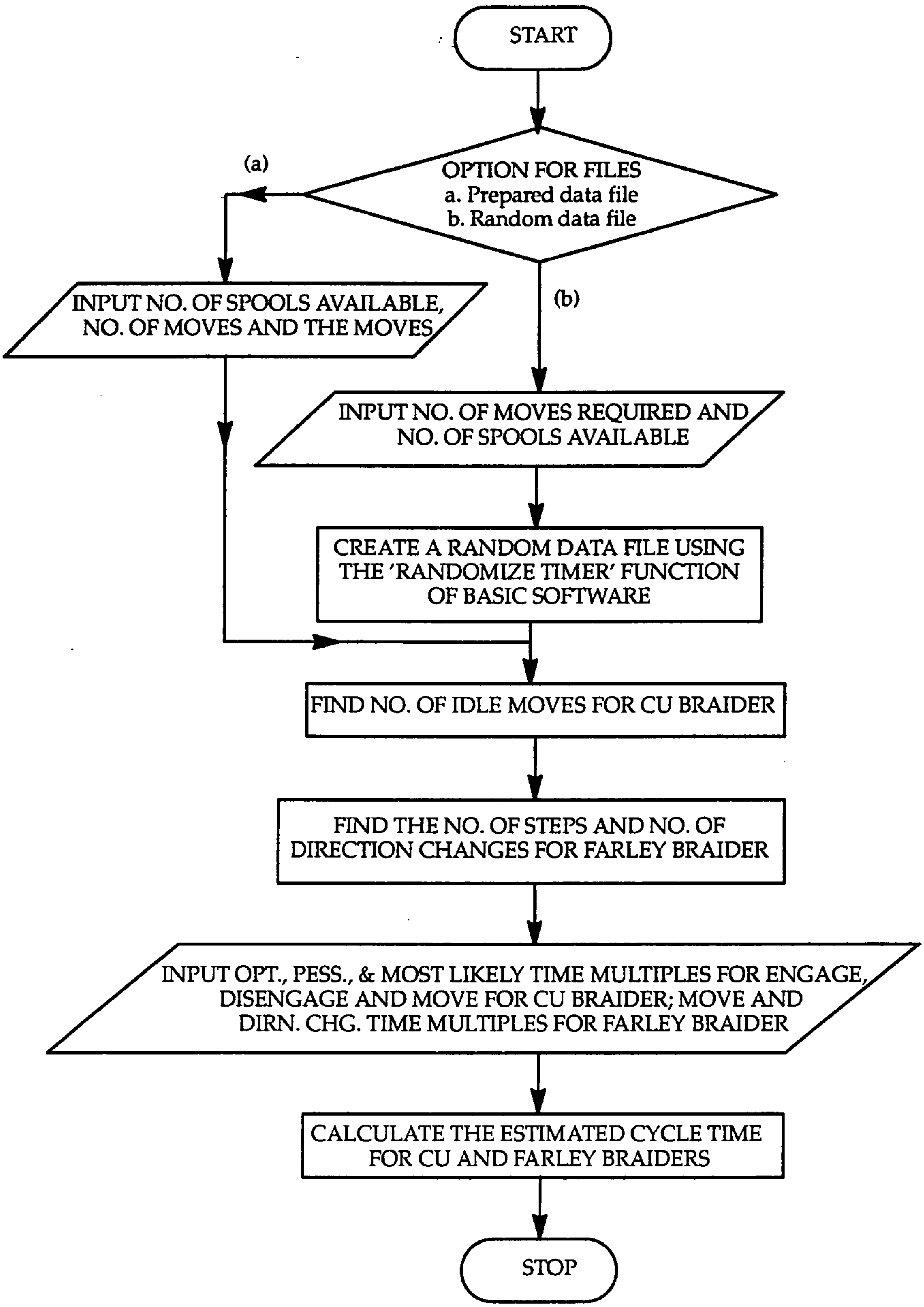

Figure G.4: Braiding Speed Study Algorithm

COMPARATIVE BRAIDING SPEED PROGRAM (PRESENT DESIGN)

```
10 CLS
20 DIM SPSTAT(100)
30 DIM BRAIDATA1$(1500)
40 DIM BRAIDATA2$(1500)
50 REM PROGRAM FOR AUTOMATIC GENERATION OF RANDOM DATA FILES
FOR COMPARISON
60 LOCATE 10,10:COLOR 3:INPUT "DO YOU WANT TO USE A PREPARED
DATA FILE <N> ";OPT$:COLOR 7
70 PRINT
80 IF OPT$<>"Y" AND OPT$<>"y" THEN OPT$="N"
90 OPEN "OUTPUT.FNL" FOR OUTPUT AS #3
100 IF OPT$<>"N" THEN 370
110 OPEN "OUT1.DAT" FOR OUTPUT AS #1
120 OPEN "OUT2.DAT" FOR OUTPUT AS #2
130 COLOR 4:INPUT "PLEASE INPUT THE NUMBER OF MOVES REQUIRED
FOR FARLEY BRAIDER ";NOFMVS
140 INPUT "PLEASE INPUT THE NUMBER OF SPOOLS AVAILABLE
";N:COLOR 7
150 RANDOMIZE TIMER
160 COMB=2^N-1
170 FOR K=1 TO NOFMVS
180 A=RND*100
190 IF A<=25 THEN DAT$="U"
200 IF A>25 AND A<=50 THEN DAT$="D"
210 IF A>50 AND A<=75 THEN DAT$="R"
220 IF A>75 THEN DAT$="L"
230 B=INT(RND*COMB)+1
```

```
240 REM BINARY DECODING
250 FOR I = 1 TO N
260 SPSTAT(I) = B MOD 2
270 B = B\2
280 NEXT I
290 REM IDENTIFICATION OF SPOOLS WHICH ARE ON
300 FOR I=1 TO N
310 IF SPSTAT(I) = 1 THEN PRINT #1, I;:PRINT #1, ",";
320 NEXT I
330 IF K=NOFMVS THEN PRINT #1, DAT$;:GOTO 360
340 PRINT #1, DAT$;:PRINT #1, ",";
350 NEXT K
360 CLOSE 1
370 OPEN "OUT1.DAT" FOR INPUT AS #1
380 IF OPT$ <> "N" THEN OPEN "OUT2.DAT" FOR OUTPUT AS #2
390 IF OPT$ <> "N" THEN INPUT #1, NOFMVS
400 IF OPT$ <> "N" THEN INPUT #1, N
410 INDX=0
420 WHILE NOT EOF (1)
430 INDX=INDX+1
440 INPUT #1, BRAIDATA2$(INDX)
450 IF BRAIDATA2$(INDX) >= "a" AND BRAIDATA2$(INDX) <= "z"
THEN BRAIDATA2$(INDX) = CHR$(ASC(BRAIDATA2$(INDX))-32)
460 WEND
470 INDX=INDX+1:BRAIDATA2$(INDX) = "E"
480 CLOSE (1)
490 NOFMVS1 = NOFMVS * 2
```

```
500 PRINT "THE MOVES FOR FARLEY BRAIDER ARE AS FOLLOWS : "
510 FOR I=1 TO INDX
520 IF I = INDX THEN PRINT BRAIDATA2$(I):GOTO 550
530 PRINT BRAIDATA2$(I)+",";
540 NEXT I
550 PRINT #3, "":PRINT #3, "NO OF SPOOLS AVAILABLE ARE ";N
560 PRINT #3, "":PRINT #3, "NO OF MOVES FOR FARLEY BRAIDER
ARE ";NOFMVS
570 PRINT #3, "":PRINT #3, "THE MOVES FOR FARLEY BRAIDER ARE
AS FOLLOWS "
580 PRINT #3, ""
590 FOR I=1 TO INDX
600 IF I = INDX THEN PRINT #3, BRAIDATA2$(I):GOTO 630
610 PRINT #3, BRAIDATA2$(I)+",";
620 NEXT I
630 I = 1:KOUNT = 1
640 FOR M = 1 TO INDX
650 FOR K = 1 TO 2
660 IF K = 2 THEN I = KOUNT
670 IF BRAIDATA2$(I) <> "U" AND BRAIDATA2$(I) <> "D" AND
BRAIDATA2$(I) <> "R" AND BRAIDATA2$(I) <> "L" THEN PRINT #2,
BRAIDATA2$(I);:PRINT #2, ",";:I = I+1:GOTO 670
680 IF BRAIDATA2$(I) = "U" OR BRAIDATA2$(I) = "D" OR
BRAIDATA2$(I) = "R" OR BRAIDATA2$(I) = "L" THEN PRINT #2,
BRAIDATA2$(I);:PRINT #2, ",";:I = I+1
690 IF K = 2 THEN KOUNT = I
700 NEXT K
```

```
710 M = KOUNT:I=KOUNT:NEXT M
720 CLOSE (2)
730 OPEN "OUT2.DAT" FOR INPUT AS #2
740 INDX1=0
750 WHILE NOT EOF (2)
760 INDX1 = INDX1+1
770 INPUT #2, BRAIDATA1$(INDX1)
780 IF BRAIDATA1$(INDX1) >= "a" AND BRAIDATA1$(INDX1) <= "z"
THEN BRAIDATA1$(INDX1) = CHR$(ASC(BRAIDATA1$(INDX1))-32)
790 WEND
800 INDX1 = INDX1+1:BRAIDATA1$(INDX1) = "E"
810 CLOSE (2)
820 PRINT
830 PRINT "SHUTTLE PLATE BRAIDER MOVES ARE AS FOLLOWS "
840 FOR I=1 TO INDX1
850 IF I = INDX1 THEN PRINT BRAIDATA1$(I):GOTO 890
860 PRINT BRAIDATA1$(I)+",";
870 NEXT I
880 PRINT #3, "":PRINT #3, "NO OF MOVES FOR SHUTTLE PLATE
BRAIDER ARE ";NOFMVS1
890 PRINT #3, "":PRINT #3, "THE MOVES FOR SHUTTLE PLATE
BRAIDER ARE AS FOLLOWS "
900 PRINT #3, ""
910 FOR I=1 TO INDX1
920 IF I = INDX1 THEN PRINT #3, BRAIDATA1$(I):GOTO 950
930 PRINT #3, BRAIDATA1$(I)+",";
940 NEXT I
```

```
950 POSN$ = "HOME":DIRN$="HOR"
960 IDLMVS = 0:MR=0:DCH=0
970 FOR I=1 TO INDX1
980 IF BRAIDATA1$(I)="U" AND POSN$="HOME" THEN
POSN$="UP":GOTO 1100
990 IF BRAIDATA1$(I)="U" AND POSN$="UP" THEN
IDLMVS=IDLMVS+1:POSN$="UP":GOTO 1100
1000 IF BRAIDATA1$(I)="U" AND POSN$="RIGHT" THEN
IDLMVS=IDLMVS+1:POSN$="UP":GOTO 1100
1010 IF BRAIDATA1$(I)="D" AND POSN$="UP" THEN
POSN$="HOME":GOTO 1100
1020 IF BRAIDATA1$(I)="D" AND POSN$="HOME" THEN
IDLMVS=IDLMVS+1:POSN$="HOME":GOTO 1100
1030 IF BRAIDATA1$(I)="D" AND POSN$="RIGHT" THEN
IDLMVS=IDLMVS+2:POSN$="HOME":GOTO 1100
1040 IF BRAIDATA1$(I)="R" AND POSN$="HOME" THEN
POSN$="RIGHT":GOTO 1100
1050 IF BRAIDATA1$(I)="R" AND POSN$="UP" THEN
IDLMVS=IDLMVS+1:POSN$="RIGHT":GOTO 1100
1060 IF BRAIDATA1$(I)="R" AND POSN$="RIGHT" THEN
IDLMVS=IDLMVS+1:POSN$="RIGHT":GOTO 1100
1070 IF BRAIDATA1$(I)="L" AND POSN$="RIGHT" THEN
POSN$="HOME":GOTO 1100
1080 IF BRAIDATA1$(I)="L" AND POSN$="UP" THEN
IDLMVS=IDLMVS+2:POSN$="HOME":GOTO 1100
1090 aw BRAIDATA1$(I)="L" AND POSN$="HOME" THEN
IDLMVS=IDLMVS+1:POSN$="HOME":GOTO 1100
```

```
1100 NEXT I
1110 PRINT "SHUTTLE PLATE BRAIDER DATA":PRINT
"****************************":PRINT "NO OF MOVES IS EQUAL
TO":PRINT NOFMVS1:PRINT "NO OF IDLE MOVES IS EQUAL TO":PRINT
IDLMVS
1120 PRINT #3,"":PRINT #3,"SHUTTLE PLATE BRAIDER DATA":PRINT
#3, "****************************"
1130 PRINT #3,"":PRINT #3,"NO OF MOVES IS EQUAL TO ";NOFMVS1
1140 PRINT #3,"":PRINT #3, "NO OF IDLE MOVES IS EQUAL
TO";IDLMVS
1150 REM INITIALIZE VARIABLES
1160 I=0:J=1:TOTSTEPS = 0: DCH=0:MAXSTP = 0
1170 DIM NSTEP(10), FSPL$(10), BRAID$(10)
1180 FOR M= 1 TO 10:NSTEP(M) = 0:FSPL$(M)="0":NEXT
1190 GROUP = 1
1200 REM READ FIRST MOVE, EXTRACT DIRECTION/ORIENTATION
1210 J=1: I = I+1
1220 WHILE (ASC(BRAIDATA2$(I)) >= 49) AND
(ASC(BRAIDATA2$(I)) <= 57)
1230 BRAID$(J)=BRAIDATA2$(I)
1240 I=I+1:J=J+1
1250 WEND
1260 BRAID$(J)=BRAIDATA2$(I)
1270 DIRN$ = BRAID$(J)
1280 IF DIRN$= "U" OR DIRN$= "D" THEN PORN = 0
1290 IF DIRN$= "R" OR DIRN$= "L" THEN PORN = 1
1300 FOR M=1 TO J-1
```

```
1310 SPLNO=ASC(BRAID$(M)) - 48
1320 NSTEP(SPLNO) = NSTEP(SPLNO) + 1
1330 FSPL$(SPLNO) = DIRN$
1340 NEXT M
1350 IF PORN = 1 THEN DCH = DCH +1
1360 REM LOOP
1370 IF I < INDX -1 THEN 1470
1380 GROUP = 0
1390 MAXSTP = 0
1400 FOR M=1 TO 10
1410 IF NSTEP(M) > MAXSTP THEN MAXSTP = NSTEP(M)
1420 NEXT M
1430 PRINT " MAXSTP " , MAXSTP
1440 TOTSTEPS = TOTSTEPS + MAXSTP
1450 PRINT :PRINT "TOTAL STEPS = " , TOTSTEPS, "DIR CHG = ",
DCH
1460 GOTO 1910
1470 REM READ NEXT MOVE
1480 J=1: I = I+1
1490 WHILE (ASC(BRAIDATA2$(I)) >= 49) AND
(ASC(BRAIDATA2$(I)) <= 57)
1500 BRAID$(J)=BRAIDATA2$(I)
1510 I=I+1:J=J+1
1520 WEND
1530 BRAID$(J)=BRAIDATA2$(I)
1540 DIRN$ = BRAID$(J)
1550 IF DIRN$= "U" OR DIRN$= "D" THEN NORN = 0
```

```
1560 IF DIRN$= "R" OR DIRN$= "L" THEN NORN = 1

1570 REM CHECKS FOR GROUPING

1580 IF PORN <> NORN THEN DCH = DCH +1: GROUP = 0

1590 IF PORN = NORN THEN 1600 ELSE 1650

1600 GROUP = 1

1610 FOR M=1 TO J-1

1620 SPLNO=ASC(BRAID$(M)) - 48

1630 IF (FSPL$(SPLNO) <> "0") AND (FSPL$(SPLNO) <> DIRN$)
THEN GROUP = 0

1640 NEXT M

1650 REM ACTIONS ON GROUPING STATUS

1660 IF GROUP = 1 THEN 1670 ELSE 1730

1670 FOR M=1 TO J-1

1680 SPLNO=ASC(BRAID$(M)) - 48

1690 NSTEP(SPLNO) = NSTEP(SPLNO) + 1

1700 FSPL$(SPLNO) = DIRN$

1710 NEXT M

1720 GOTO 1900

1730 IF GROUP = 0 THEN 1750 ELSE 1900

1740 REM FIND MAX STEP

1750 MAXSTP = 0

1760 FOR M=1 TO 10

1770 IF NSTEP(M) > MAXSTP THEN MAXSTP = NSTEP(M)

1780 NEXT M

1790 PRINT " MAXSTP " , MAXSTP:TOTSTEPS = TOTSTEPS + MAXSTP

1800 REM INITIALIZE

1810 FOR M= 1 TO 10:NSTEP(M) = 0:FSPL$(M)="0":NEXT
```

```
1820 REM UPDATE FOR NEW GROUP
1830 FOR M=1 TO J-1
1840 SPLNO=ASC(BRAID$(M)) - 48
1850 NSTEP(SPLNO) = NSTEP(SPLNO) + 1
1860 FSPL$(SPLNO) = DIRN$
1870 NEXT M
1880 GROUP = 1
1890 PORN = NORN
1900 GOTO 1360
1910 PRINT ""
1920 PRINT "":PRINT "FARLEY BRAIDER DATA":PRINT
"*******************":PRINT "NO OF STEPS IS EQUAL TO
";TOTSTEPS:PRINT "NO OF DIRECTION CHANGES EQUAL TO";DCH
1930 PRINT #3,"":PRINT #3,"FARLEY BRAIDER DATA":PRINT #3,
"*******************"
1940 PRINT #3,"":PRINT #3, "NO OF STEPS IS EQUAL TO
";TOTSTEPS
1950 PRINT #3, "":PRINT #3, "NO OF DIRECTION CHANGES IS
EQUAL TO ";DCH
1960 REM CALCULATION OF CYCLE TIMES
1970 PRINT #3, " "
1980 PRINT #3, " ":PRINT #3, "DETAILS OF CYCLE TIME FOR
SHUTTLE PLATE BRAIDER ARE AS FOLLOWS "
1990 PRINT #3,
"************************************************************
*** "
2000 PRINT ""
```

```
2010 PRINT "PLEASE INPUT THE FOLLOWING TIMES "
2020 PRINT "********************************* "
2030 INPUT "PLEASE INPUT THE OPTIMISTIC ENGAGE TIME MULTIPLE
FOR SHUTTLE PLATE BRAIDER ";ETO
2040 INPUT "PLEASE INPUT THE PESSIMISTIC ENGAGE TIME
MULTIPLE FOR SHUTTLE PLATE BRAIDER ";ETP
2050 INPUT "PLEASE INPUT THE MOST LIKELY ENGAGE TIME
MULTIPLE FOR SHUTTLE PLATE BRAIDER ";ETM
2060 PRINT #3, "":PRINT #3, "OPTIMISTIC ENGAGE TIME MULTIPLE
FOR SHUTTLE PLATE BRAIDER IS EQUAL TO ";:PRINT #3, ETO
2070 PRINT #3, "":PRINT #3, "PESSIMISTIC ENGAGE TIME
MULTIPLE FOR SHUTTLE PLATE BRAIDER IS EQUAL TO ";:PRINT #3,
ETP
2080 PRINT #3, "":PRINT #3, "MOST LIKELY ENGAGE TIME
MULTIPLE FOR SHUTTLE PLATE BRAIDER IS EQUAL TO ";:PRINT #3,
ETM
2090 PRINT
2100 INPUT "PLEASE INPUT THE OPTIMISTIC DISENGAGE TIME
MULTIPLE FOR SHUTTLE PLATE BRAIDER ";DEO
2110 INPUT "PLEASE INPUT THE PESSIMISTIC DISENGAGE TIME
MULTIPLE FOR SHUTTLE PLATE BRAIDER ";DEP
2120 INPUT "PLEASE INPUT THE MOST LIKELY DISENGAGE TIME
MULTIPLE FOR SHUTTLE PLATE BRAIDER ";DEM
2130 PRINT #3, "":PRINT #3, "OPTIMISTIC DISENGAGE TIME
MULTIPLE FOR SHUTTLE PLATE BRAIDER IS EQUAL TO ";DEO
2140 PRINT #3, "":PRINT #3, "PESSIMISTIC DISENGAGE TIME
MULTIPLE FOR SHUTTLE PLATE BRAIDER IS EQUAL TO ";DEP
```

```
2150 PRINT #3, "":PRINT #3, "MOST LIKELY DISENGAGE TIME
MULTIPLE FOR SHUTTLE PLATE BRAIDER IS EQUAL TO ";DEM
2160 PRINT
2170 INPUT "PLEASE INPUT THE OPTIMISTIC MACHINE TIME
MULTIPLE FOR SHUTTLE PLATE BRAIDER ";MTO1
2180 INPUT "PLEASE INPUT THE PESSIMISTIC MACHINE TIME
MULTIPLE FOR SHUTTLE PLATE BRAIDER ";MTP1
2190 INPUT "PLEASE INPUT THE MOST LIKELY MACHINE TIME
MULTIPLE FOR SHUTTLE PLATE BRAIDER ";MTM1
2200 PRINT #3, "":PRINT #3, "OPTIMISTIC MACHINE TIME
MULTIPLE FOR SHUTTLE PLATE BRAIDER IS EQUAL TO ";MTO1
2210 PRINT #3, "":PRINT #3, "PESSIMISTIC MACHINE TIME
MULTIPLE FOR SHUTTLE PLATE BRAIDER IS EQUAL TO ";MTP1
2220 PRINT #3, "":PRINT #3, "MOST LIKELY MACHINE TIME
MULTIPLE FOR SHUTTLE PLATE BRAIDER IS EQUAL TO ";MTM1
2230
CYCTIMEO=(NOFMVS1)*(ETO)+(NOFMVS1)*(DEO)+(NOFMVS1)*(MTO1)+(I
DLMVS)*(MTO1)
2240
CYCTIMEP=(NOFMVS1)*(ETP)+(NOFMVS1)*(DEP)+(NOFMVS1)*(MTP1)+(I
DLMVS)*(MTP1)
2250
CYCTIMEM=(NOFMVS1)*(ETM)+(NOFMVS1)*(DEM)+(NOFMVS1)*(MTM1)+(I
DLMVS)*(MTM1)
2260 CYCTIMEE=(CYCTIMEO+4*CYCTIMEM+CYCTIMEP)/6
2270 PRINT
2280 PRINT "FOR SHUTTLE PLATE BRAIDER THE TOTAL CYCLE TIMES
```

```
ARE AS FOLLOWS "
2290 PRINT
2300 PRINT "OPTIMISTIC TIME IS EQUAL TO ";CYCTIMEO;:PRINT
"UNITS"
2310 PRINT "PESSIMISTIC TIME IS EQUAL TO ";CYCTIMEP;:PRINT
"UNITS"
2320 PRINT "MOST LIKELY TIME IS EQUAL TO ";CYCTIMEM;:PRINT
"UNITS"
2330 PRINT "THE ESTIMATED CYCLE TIME IS EQUAL TO
";CYCTIMEE;:PRINT "UNITS"
2340 PRINT #3, " "
2350 PRINT #3, "FOR SHUTTLE PLATE BRAIDER THE TOTAL CYCLE
TIMES ARE AS FOLLOWS "
2360 PRINT #3,
"*************************************************************
***"
2370 PRINT #3, " "
2380 PRINT #3, "OPTIMISTIC TIME IS EQUAL TO
";CYCTIMEO;:PRINT #3, "  UNITS"
2390 PRINT #3, ""
2400 PRINT #3, "PESSIMISTIC TIME IS EQUAL TO
";CYCTIMEP;:PRINT #3, "  UNITS"
2410 PRINT #3, ""
2420 PRINT #3, "MOST LIKELY TIME IS EQUAL TO
";CYCTIMEM;:PRINT #3, "  UNITS"
2430 PRINT #3, " "
2440 PRINT #3, "THE ESTIMATED CYCLE TIME IS EQUAL TO
```

```
";CYCTIMEE;:PRINT #3, "  UNITS"
2450 PRINT #3, " "
2460 PRINT #3, "DETAILS OF CYCLE TIME FOR FARLEY BRAIDER ARE
AS FOLLOWS "
2470 PRINT #3,
"********************************************************** "
2480 PRINT
2490 INPUT "PLEASE INPUT THE OPTIMISTIC DIRECTION CHANGE
TIME MULTIPLE FOR FARLEY BRAIDER ";DCHTO
2500 INPUT "PLEASE INPUT THE PESSIMISTIC DIRECTION CHANGE
TIME MULTIPLE FOR FARLEY BRAIDER ";DCHTP
2510 INPUT "PLEASE INPUT THE MOST LIKELY DIRECTION CHANGE
TIME MULTIPLE FOR FARLEY BRAIDER ";DCHTM
2520 PRINT #3, ""
2530 PRINT #3,"OPTIMISTIC DIRECTION CHANGE TIME MULTIPLE FOR
FARLEY BRAIDER IS EQUAL TO ";DCHTO
2540 PRINT #3, "":PRINT #3,"PESSIMISTIC DIRECTION CHANGE
TIME MULTIPLE FOR FARLEY BRAIDER IS EQUAL TO ";DCHTP
2550 PRINT #3, "":PRINT #3,"MOST LIKELY DIRECTION CHANGE
TIME MULTIPLE FOR FARLEY BRAIDER IS EQUAL TO ";DCHTM
2560 PRINT
2570 INPUT "PLEASE INPUT THE OPTIMISTIC MACHINE TIME
MULTIPLE FOR FARLEY BRAIDER ";MTO2
2580 INPUT "PLEASE INPUT THE PESSIMISTIC MACHINE TIME
MULTIPLE FOR FARLEY BRAIDER ";MTP2
2590 INPUT "PLEASE INPUT THE MOST LIKELY MACHINE TIME
MULTIPLE FOR FARLEY BRAIDER ";MTM2
```

```
2600 PRINT #3,""
2610 PRINT #3, "":PRINT #3,"OPTIMISTIC MACHINE TIME MULTIPLE
FOR FARLEY BRAIDER IS EQUAL TO";MTO2
2620 PRINT #3, "":PRINT #3,"PESSIMISTIC MACHINE TIME
MULTIPLE FOR FARLEY BRAIDER IS EQUAL TO";MTP2
2630 PRINT #3, "":PRINT #3,"MOST LIKELY MACHINE TIME
MULTIPLE FOR FARLEY BRAIDER IS EQUAL TO";MTM2
2640 CYCTIMEO2=(DCH)*(DCHTO)+(TOTSTEPS)*(MTO2)
2650 CYCTIMEP2=(DCH)*(DCHTP)+(TOTSTEPS)*(MTP2)
2660 CYCTIMEM2=(DCH)*(DCHTM)+(TOTSTEPS)*(MTM2)
2670 CYCTIMEE2=(CYCTIMEO2+4*CYCTIMEM2+CYCTIMEP2)/6
2680 PRINT #3, " "
2690 PRINT
2700 PRINT "FOR FARLEY BRAIDER THE TOTAL CYCLE TIMES ARE
FOLLOWS "
2710 PRINT
2720 PRINT "OPTIMISTIC TIME IS EQUAL TO ";CYCTIMEO2;:PRINT
"UNITS"
2730 PRINT "PESSIMISTIC TIME IS EQUAL TO ";CYCTIMEP2;:PRINT
"UNITS"
2740 PRINT "MOST LIKELY TIME IS EQUAL TO ";CYCTIMEM2;:PRINT
"UNITS"
2750 PRINT "THE ESTIMATED CYCLE TIME IS EQUAL TO
";CYCTIMEE2;:PRINT "UNITS"
2760 PRINT #3, "FOR FARLEY BRAIDER THE TOTAL CYCLE TIMES ARE
FOLLOWS "
2770 PRINT #3,
```

```
"*******************************************************"
2780 PRINT #3, " "
2790 PRINT #3, "OPTIMISTIC TIME IS EQUAL TO
";CYCTIMEO2;:PRINT #3, "  UNITS"
2800 PRINT #3, ""
2810 PRINT #3, "PESSIMISTIC TIME IS EQUAL TO
";CYCTIMEP2;:PRINT #3, "  UNITS"
2820 PRINT #3, ""
2830 PRINT #3, "MOST LIKELY TIME IS EQUAL TO
";CYCTIMEM2;:PRINT #3, "  UNITS"
2840 PRINT #3, ""
2850 PRINT #3, "THE ESTIMATED CYCLE TIME IS EQUAL TO
";CYCTIMEE2;:PRINT #3, "  UNITS"
2860 CLOSE (3)
```

Appendix H:

Student Preliminary Study

ME841 NASA Design Group

"Mechanism for the Fabrication

of 3-D Composite Structures"

August 18, 1988
to
December 9, 1988

Submitted to:

Dr. M. W. Dixon

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CHAPTER 1

INTRODUCTION

Background

In the aerospace industry, recent advances in applications for composite materials have created many new demands upon existing manufacturing processes. Though composite materials have been widely used for several decades, the actual fabrication of most of the structures which use composite materials has not changed significantly. Usually, a composite structure is made up of layers of fibers, oriented in different directions, which may or may not be interwoven within a given layer. A matrix material surrounds the fibers to prevent them from moving and to add rigidity to the structure. The fibers are used to transmit the internal stresses in the structure. For this reason, the orientation and placement of these fibers is critical to the performance characteristics of the finished part.

One disadvantage of this construction is the tendency for the individual layers of the composite laminate to separate from each other when the part is stressed in certain ways. This tendency is called de-lamination. As a result of this tendency, several schemes have been devised for reducing or eliminating this possibility.

One approach is to stitch the layers together, much like layers of fabric. This approach has been tried with some success. However, the stitching processes used to date have caused damage to as much as ten percent of the composite fibers within the laminate. This damage is caused by the stitching needle as it passes through the layers of fibers. Testing of stitched composites has indicated that the tensile strength of these structures is not adversely affected by the damage in some cases, or can be designed for in other cases. The effects upon the fatigue life for such structures could be detrimental, however. Testing for the effects of stitching damage upon the fatigue life of composite

laminates is currently being conducted. The major advantage of this method is the overall simplicity of the stitching process. It is easily implemented with current technology.

Another approach is to circumvent the layered approach altogether, and create the structure as one piece in the first place. While this may seem to be the obvious choice for maximum performance of the composite structure, actual fabrication of such a part involves many difficulties which are prohibitive. Most of the endeavors to create thick composite structures have involved modification of existing weaving and braiding technology. This has met limited success, but at great cost, and only in certain areas. A concerted effort to examine the needs of the aerospace industry for three-dimensional composite structures, and determine some of the required processes is needed.

Overview of the Work Done

An examination of the more important needs for the composite structures which would benefit the aerospace industry was conducted by this design group. Also, the determination of an objective for a four month design project was established. The various steps in the design process were performed up to the preliminary design phase. The remaining alternative methods for combining composite fibers to produce three-dimensional parts were evaluated to determine the critical requirements for each. This was done to allow future research efforts in this area to focus upon the critical parts of the design(s) first. Several recommendations were also made concerning which alternatives should be developed in the future.

CHAPTER 2

NEEDS AND OBJECTIVES

Needs for the Design Project

When our design group was first introduced to the problems which NASA was experiencing, it was apparent that some objectives for the semester had to be set. Before this was done, NASA's needs had to be determined from the information which was given to us, as outlined below. NASA posed several of the requirements for the creation of three-dimensional composite structures. These became guidelines for the research which we conducted throughout the semester. The requirements generally fell into two categories; weaving and braiding.

In most conventional weaving processes, there are two directions in which the fibers to be woven can lie. The longitudinal fibers, called warps, are usually fed continuously from large supply rollers. They pass through healds which move different sets of the fibers up and down with respect to each other. The transverse fibers, called wefts or fill fibers are passed back and forth between sets of the warps, and perpendicular to them, such that a woven layer of interlocking fibers is produced. The fibers are usually packed together to form a tightly woven structure by a device known as a reed. The reed has fins which project through the warps and push the wefts together between successive weft insertions. This process is known as the beat-up.

Some of the requirements posed by NASA included providing a means by which additional fibers which were not aligned with the conventional directions be added to the weaving process. It was considered desirable to include fibers which were in the same plane as the warp and weft, but at some angle relative to them. These fibers are called bias fibers. These fibers would carry the shear stresses which can develop in flat panels, such as those found on aircraft wings. Also, if a multi-layer woven product were to be formed, an additional requirement was to

include fibers which passed through the thickness of the product. These fibers are called through-the-thickness, or Z fibers. It has been found that incorporation of these Z fibers into a composite structure increases the damage tolerance of the structure, which is a definite advantage in the aerospace industry.

One side effect of the incorporation of bias fibers into a woven product is that the diagonal orientation of the bias fibers makes beat-up with a conventional reed difficult. The bias fibers are in the way of the reed as it tries to beat against the weft. It is apparent that the fibers could become entangled or damaged with conventional weaving methods. It would therefore be advantageous to modify the beat-up process to incorporate the bias fibers as well.

Another requirement was the ability to incorporate stiffeners onto flat panels. Conventionally, such stiffeners are manufactured as separate parts and then attached to flat panels using either stitching before adding the matrix material, or some type of mechanical fastener after curing the composite parts. An obvious advantage of being able to incorporate these stiffeners into flat panels is the reduction of hardware and labor required for assembly. Typically, titanium fasteners are needed to attach composite parts together because of the corrosive effects of the resins used in the matrix materials in composites. Also, the holes through which these fasteners pass must be carefully made and finished to avoid unnecessary breakage of fibers. These factors add significantly to the cost of mechanically fastened joints in composite structures. Elimination of these mechanical fasteners will make composites more cost effective in future applications.

In addition to the above requirements, it was also required to be able to vary the cross-section of the woven structure during fabrication. For instance, a multi-layered flat panel could have some stiffeners which tapered into the flat part of the panel, rather than stopping abruptly, in order to reduce stress concentrations. This

requirement was not stressed as heavily as the others concerning weaving, but it encompasses many possibilities for manufacturing.

Conventional braiding consists of passing several fibers around each other such that they form a pre-determined pattern which creates the product. This process is used to make many types of ropes and cables. It is widely used for other products as well, such as shoe laces and elastic. In some cases, fixed fibers are held in place while other fibers are braided around them to bind them together.

Almost always, a given braiding machine can produce only one pattern of braid. This is primarily because of the method used by most braiding machines to move the individual fibers around each other. The fibers are wound onto spools or carriers which move in a track on the braider. The spools are forced to move by the rotation of various wheels beneath the track which are slotted to accept the bottom ends of the carriers. The motion of the spools passes the fibers around each other to create the braid and pull the fiber from the spools.

In the aerospace industry, many of the composite parts which have thick cross-sections could possibly be braided. For many of the parts which could be braided, the ability to vary the cross-sectional properties of the part along its length would be of great use. For instance, some of the structural members in airframes could be designed to buckle in a certain way by changing the cross-sectional shape or stiffness in some sections. Thus, the airframe could be designed to absorb energy in a crash landing. However, the fixed nature of most of the conventional braiding processes has precluded this possibility.

One of the requirements made by NASA was to investigate the design of a braiding machine which could create a wide variety of patterns by selecting the individual path for each fiber to be braided. This requirement has resulted in the phrase "Move any fiber to any point through any path". This would allow the maximum amount of flexibility in the manufacture of braided composite parts.

An additional requirement for the braiding of composites is the ability to change the angle of the path taken by the individual fibers as they are incorporated into the product. This controls the tightness of the packing of the fibers within the structure, which controls the stiffness and damage tolerance of the part. Most conventional braiders have limited provisions for adjusting this braiding angle. The production of irregular shapes with tightly-packed fibers will require some sort of control over this angle or some other means of insuring a dense structure. If some other means for producing a tightly-packed, braided structure can be found, it would be equally beneficial for the manufacture of composite parts.

The preceding discussion on the requirements of the design project is summarized in Table 1.

Table 1

Weaving:

1. The ability to incorporate bias fibers in any direction within a layer of the product,
2. The ability to incorporate bias fibers in any layer of a multi-layered product,
3. The ability to incorporate stiffeners for flat panels,
4. The ability to vary the size and shape of such stiffeners.

Braiding:

1. The ability to produce any pattern of braided fibers,
2. The ability to vary the braiding pattern and cross-section shape along the length of a braided product,
3. The ability to control the tightness of the packing of the fibers within the braided product.

Objectives for the Design Project

All of the requirements discussed before seem to encompass an enormous array of possibilities when viewed as requirements for weaving and braiding processes. However, we chose to view all of the requirements in terms of the creation of composite products, regardless of the method used to combine the fibers. In fact, it can be shown that weaving and braiding are simply variations of the same process, intertwining individual fibers in an orderly, pre-determined manner to produce an object.

It is unlikely that a single machine could be designed to efficiently and reliably manufacture all possible types of fiber products. However, by taking a more fundamental viewpoint concerning the methods used to combine fibers to create a product, we felt that some of the limitations of thinking in terms of only weaving or braiding could be avoided. Thus, we could create more concepts which did not necessarily fall into either weaving or braiding categories, but might be beneficial to the future production of three-dimensional composite structures.

It was decided by the members of the design group that we should not only investigate the possible solutions to the requirements posed by NASA, but also provide some insight into the details of each of the designs which are feasible. This includes not only some preliminary design work, but recommendations for future work. One area in particular, is the determination of the critical processes in each design. This is needed so that if further research is conducted on any of the concepts, the more critical design problems can be addressed first. If these cannot be solved practically, there is no point in continuing with the design. Having the topics for such additional research highlighted will be of great benefit to future work in this area.

The resulting objectives for the semester design project were the result of consideration of the needs of NASA and the requirements for future research in the area of three-dimensional composite structures. These objectives can be summarized in Table 2.

Table 2

1. Define a set of alternative preliminary designs which can create three-dimensional composite products which incorporate

    a. variability of fiber orientation within the product,

    b. stiffeners which are integral with the product,

    c. through-the-thickness fibers within the product,

    d. control of tightness of packing of fibers within the product.

    These features must be consistent with the needs stated previously.

2. Determine the critical factors governing each design so that future research can focus upon these problems first.

CHAPTER 3

DEFINITIONS

Product Geometry Types

Because of the wide variety of possible configurations for the overall geometry of a product which could be made from composite fibers, we decided to classify the types of geometries. We decided upon five geometry types. They are listed here in order of complexity:

1. single layer,
2. multi-layer with constant thickness and cross-section,
3. multi-layer with varying thickness and constant cross-section,
4. multi-layer with constant thickness and varying cross-section,
5. complex cross-section.

A single layer geometry is the simplest type. It is merely a single layer of fibers, resembling fabric. A multi-layer geometry consists of more than one layer of fibers combined into a single part. The term multi-layer is used only to imply more than one fiber thickness, not an actual layered construction. Thus, it is independent of the method used to combine the fibers (weaving, braiding, etc.). If the thickness of a multi-layer part varies, this means that the part is first produced with one thickness, then the thickness is changed for another section of the part as it is made. At any given time, the cross-section of the part is uniform across its width. If the cross-section of a multi-layer part varies, this means that the cross-section of the part is not uniform across the width of the part, but the cross-section does not change along the length of the part. The complex cross-section geometry is a combination of varying thickness and cross-section. This geometry also includes irregular

shapes and multiply-connected cross-sections (cross-sections containing holes). Representations of the different geometry types are shown in Figure 1.

Fiber Combination Types

Along with the product geometry types, we defined four fiber combination types. Even though we made every effort to develop concepts without consideration of any one type of manufacturing process, the evaluation of the capabilities of each of the designs required the classification of several types of manufacturing processes for combining fibers.

All of the definitions for the fiber combination types rely on the same terminology, which is then expanded in some cases to include existing terminology, where applicable. This terminology consists of three types of fibers. There are longitudinal fibers which are parallel to the direction of production of the product, and usually run the length of the product. Transverse fibers are generally perpendicular to the longitudinal fibers and run across the width of the product. They may also be considered to run through the thickness of the product, again, perpendicular to the longitudinal fibers. Finally, there are angled fibers which are not parallel to either the longitudinal fibers or transverse fibers. There is no other restriction upon their orientation.

Four fiber combination types were defined, as follows:

1. weaving,
2. semi-weaving,
3. semi-braiding,
4. braiding.

Weaving consists of longitudinal fibers which alternately cross over and under the transverse fibers to form an interlocking pattern as

shown in Figure 2. The longitudinal fibers which are adjacent are not necessarily parallel, since they may alternately pass over and under a given transverse fiber. The longitudinal fibers are called warps and the transverse fibers are called weft in traditional weaving processes. Weaving may also have angled fibers which are in the plane of the warp and weft fibers, called bias fibers. Weaving may also have transverse fibers perpendicular to the warp and weft fibers which are called through-the-thickness fibers or Z fibers. These may simply be warp fibers which traverse the entire thickness of the product, or they may be independent of the warp fibers.

Semi-weaving consists of layers of longitudinal fibers (warps) which are parallel, alternating with layers of transverse fibers (wefts), which are parallel to each other but perpendicular to the longitudinal fibers, as shown in Figure 3. Angled fibers (bias) may also be present in layers. Because no interlocking occurs, additional through-the-thickness fibers must be used to bind the layers together. Note that semi-weaving is simply a modification of weaving. The only difference between the two is that in semi-woven materials, the warps and wefts do not interlock with each other, while in woven materials, they do.

Semi-braiding consists of a number of longitudinal fibers which are always parallel. They are not necessarily in layers, and are no longer called warps for that reason. There are also angled fibers which interlock with the longitudinal fibers to form the product as shown in Figure 4. Transverse fibers can be used, but are not needed. For this exercise, the transverse fibers are considered angled fibers which happen to be perpendicular to the longitudinal fibers. The reason for this is that in this geometry, a single angled fiber may traverse the thickness or width of the product many times, changing direction when necessary. Thus, an angled fiber might conceivably cross through the product perpendicular to the longitudinal fibers. This is similar to semi-weaving except for the absence of independent transverse fibers,

even though they can be simulated with the angled fibers. Note again the transition from one geometry to another with a simple modification.

Finally, braiding consists of angled fibers only. The angled fibers are twisted around each other to form an interlocking pattern by themselves, as shown in Figure 5. There are no restrictions upon the directions which the fibers may take, or whether they pass entirely through the thickness or across the width. This is the simplest transition from one geometry to another, since only the removal of the longitudinal fibers from the semi-braiding is required.

Upon examining the four fiber combination types, several trends become apparent. Probably the most obvious trend is that as one moves from weaving to braiding, the number of different types of possible fibers diminishes from four for weaving to one for braiding. This implies two things. It implies that the braiding process will have fewer different types of fiber sources. Also, less obviously, it implies that a device that can braid can probably be used to perform weaving (or other geometries). This is because the angled fibers used in braiding can be used for warp, weft, through-the-thickness, or bias fibers. The reverse is not true, however. A weaving machine cannot necessarily braid.

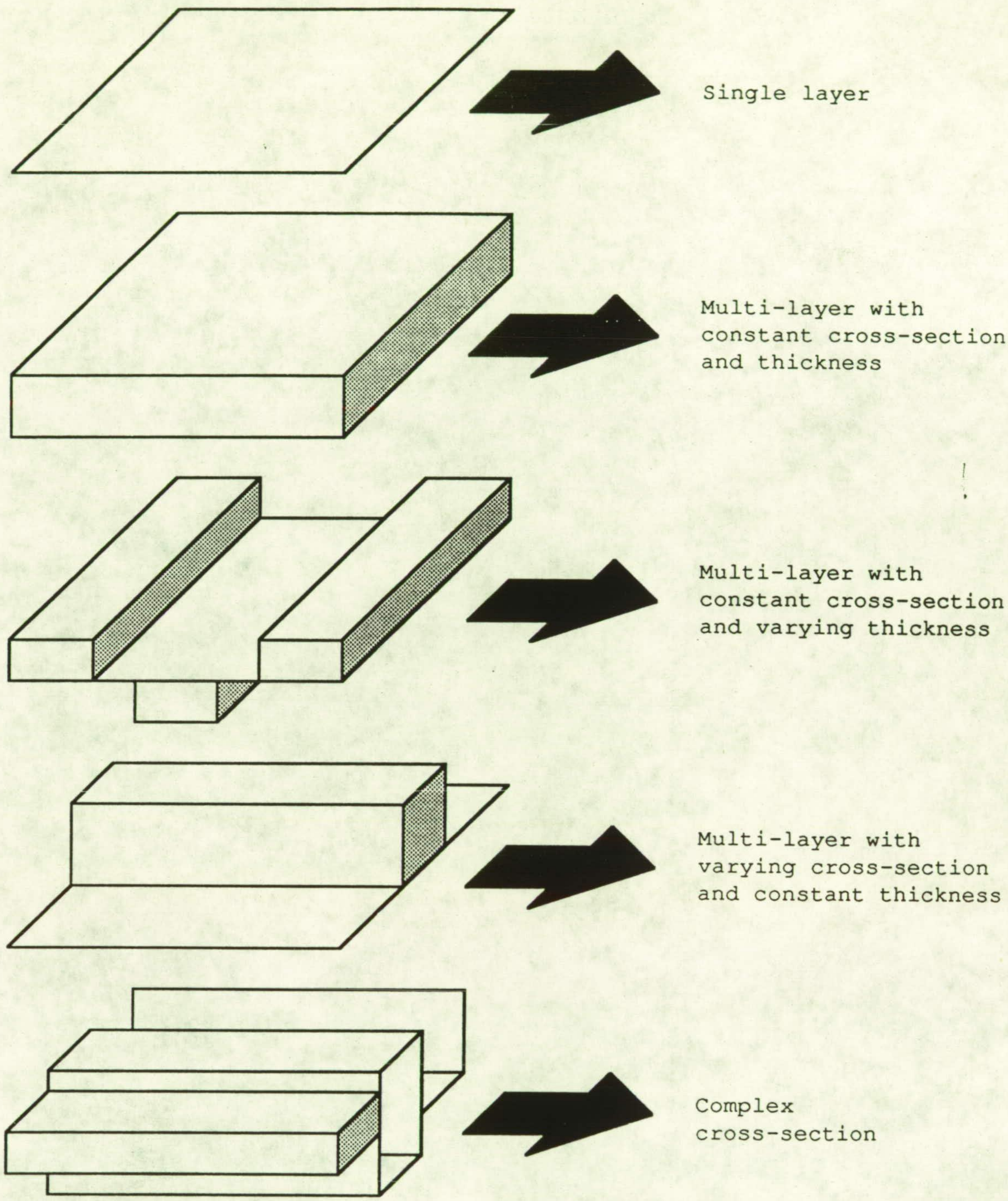


Figure 1. Product Geometry Types

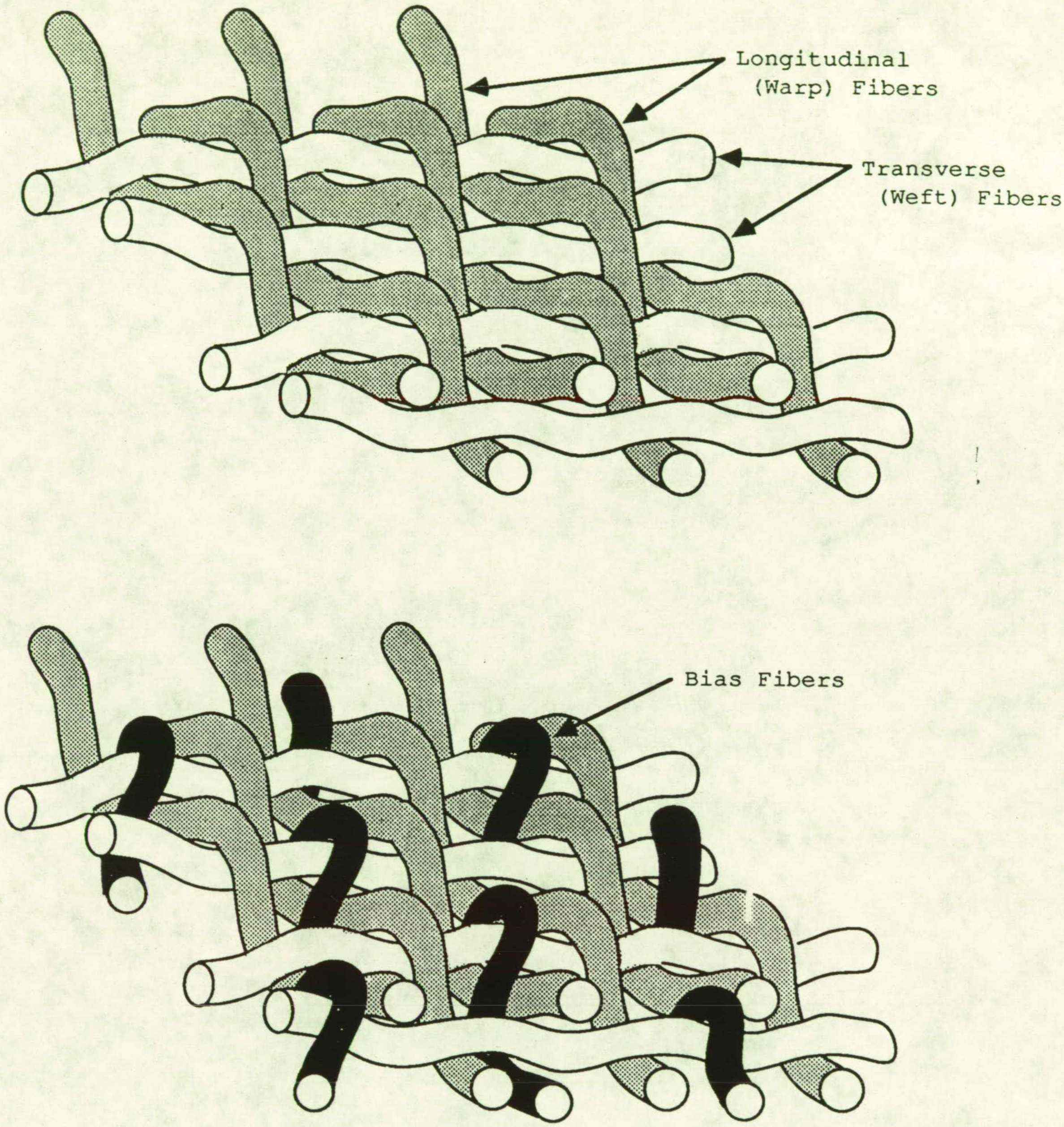


Figure 2. Weaving Fiber Combination Type

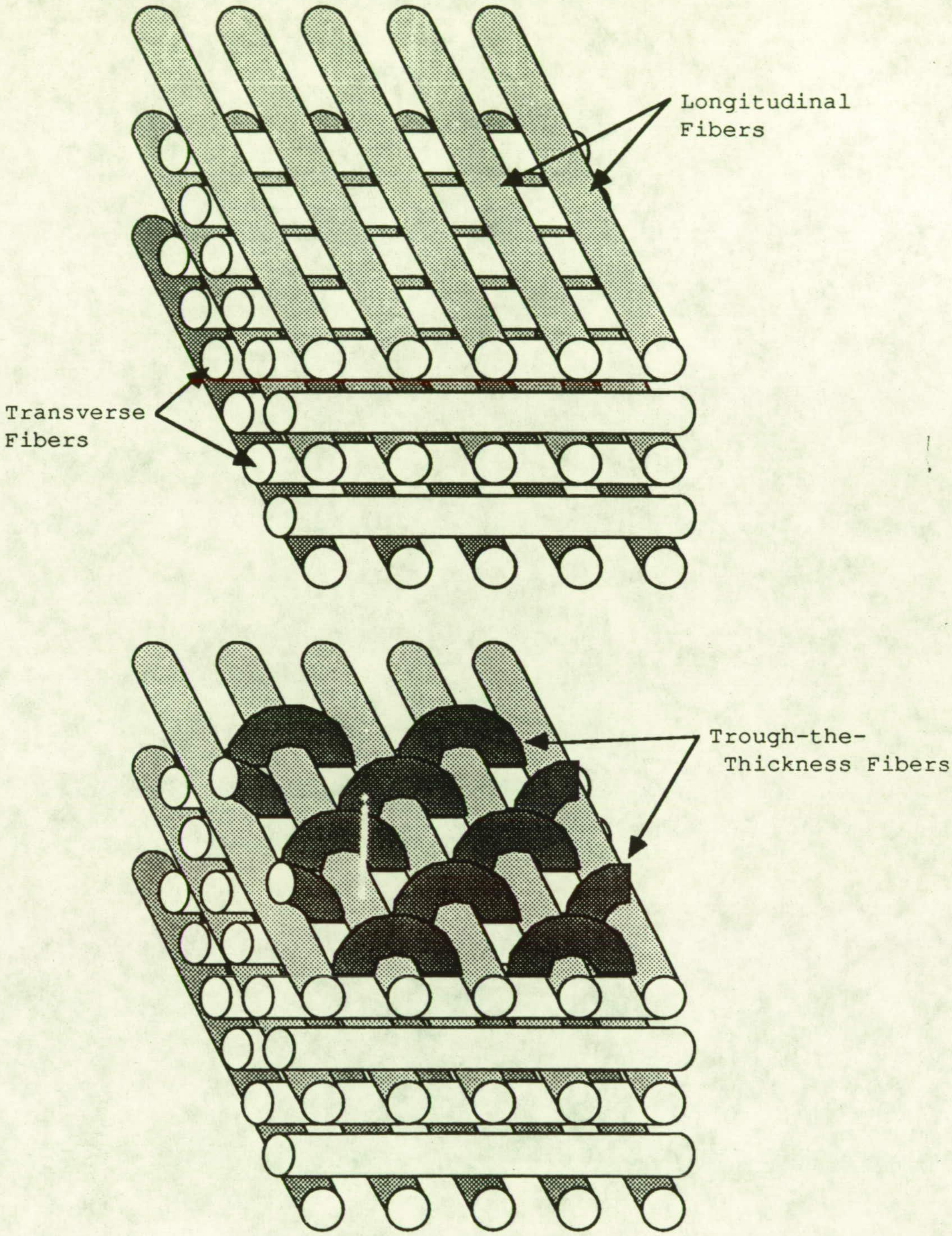


Figure 3. Semi-Weaving Fiber Combination Type

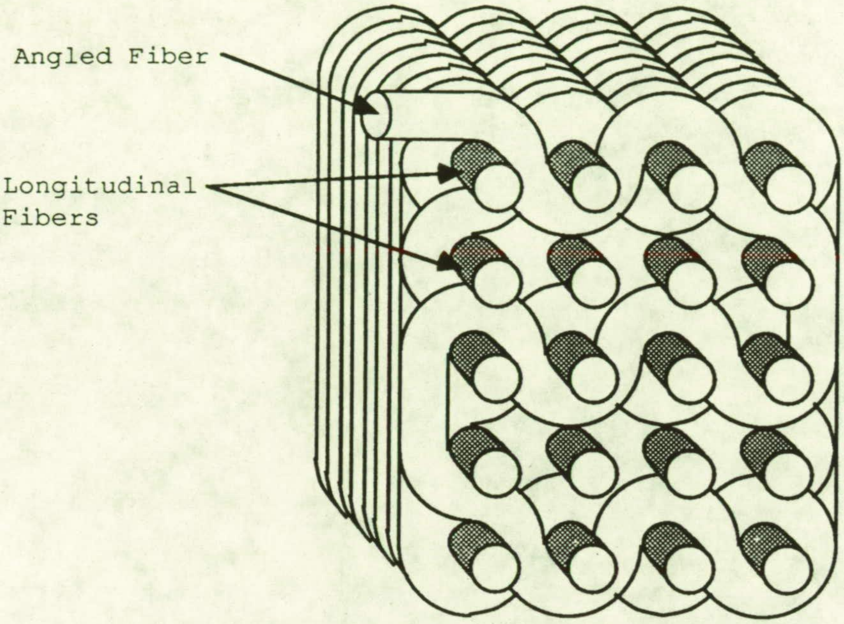


Figure 4. Semi-Braiding Fiber Combination Type

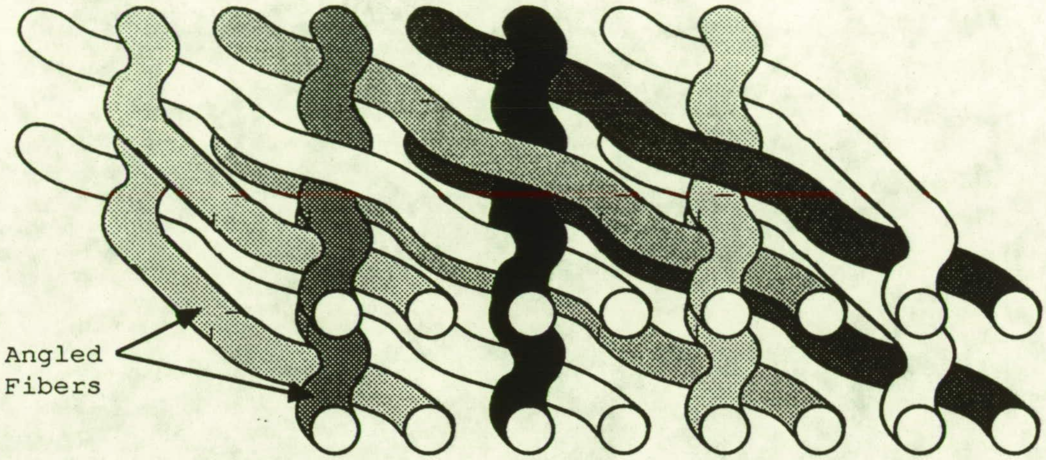


Figure 5. Braiding Fiber Combination Type

CHAPTER 4

TARGET SPECIFICATIONS

Before actually generating a list of concepts for our design, it was necessary to develop a list of target specifications for the design. With so many possible processes which might be used to satisfy the requirements of NASA, it was difficult to produce a comprehensive list of specifications. The overall specifications were broken into categories, listed in Table 3.

Table 3

1. damage tolerance of the fibers used to make the product,
2. the diameter of the fibers used to make the product,
3. size of the object to be made,
4. the number of fiber bundles to be used for making the product,
5. fiber angle variation,
6. amount of through-the-thickness fibers in the product,
7. fiber tension variation,
8. speed of production.

Damage Tolerance of Fibers

Concerning the damage tolerance of the fibers used to make the product, there are two possible reasons why a fiber might be damaged or broken. A fiber may be placed in tension until tensile failure, or it may be bent until bending failure occurs. Since composite fibers are used because of their excellent tensile strength, we felt that this would not be a critical concern for any of the processes which might be used to fabricate a composite structure. However, the minimum radius about which a composite fiber may be bent could definitely be a critical concern.

It was decided to first determine the most fragile type of fiber which might be used in such a product. Unfortunately, there are many types of composite fibers in use today which have a wide variety of mechanical properties. This made the task of eliminating all possibility of fiber damage difficult. We therefore decided to assume that the more common types of carbon, kevlar and glass fibers would be used. In all cases, the fibers have excellent bending tolerance. This is because the diameter of the individual fibers used to make a fiber bundle are extremely small, on the order of microns in diameter. After consulting with some local experts of composite materials, we decided upon limiting the bending radius of all composite fiber bundles to 0.1 inches. Even this small dimension allowed a significant factor of safety for almost all of the fiber types.

During our research, we discovered that many of the more fragile fibers presently in use for the manufacture of composites are often wrapped, or served, so that the fibers can support each other and not be broken. This serving fiber which wraps around the other fibers in the bundle is removed once the product has been fabricated, either with heat or with chemicals. Knowing this, there is no conceivable reason why these more fragile fibers could not also be used with the 0.1 inch bending radius.

Size of Fiber Bundles

The actual size of the fiber bundles used to fabricate the composite structure may vary significantly, even within the same part. The suggested range for the fiber bundles used most often was between 0.035 and 0.6 millimeters (about 0.0015 and 0.025 inches) in diameter. This range covers what NASA is currently using in its experiments with three-dimensional composite structures.

Size of Composite Object

The size of the composite object to be created is significant when designing the machinery to perform the fabrication of the object. When NASA first communicated their desires for the composite fabrication, we were told that there would be two distinct phases in the design of the manufacturing process. The first phase, the prototype phase, would require products of relatively small size. The product would only have to be large enough to demonstrate the concept. Later, the second phase would involve significantly larger products used in production.

We decided to base the product sizes upon what NASA suggested, and divided the specifications into the different product geometry types. For relatively flat geometries such as single layer or multi-layer products with relatively small ribs, the prototype size for the product would be approximately twelve inches wide. Once production is considered, this dimension could be scaled up to twelve feet or larger. Most of the flat products which are being fabricated today can be made at least twelve feet in width and larger. For the more complex product geometries, the prototype size for the product would be approximately three to five inches square. Once production is considered, products as large as twelve inches square may be produced.

Number of Fiber Bundles

The number of fiber bundles was a difficult specification to pin down, because it is dependent upon the product size, the method used for fabrication, and the diameter of the fiber bundles used. However, we felt that the number of fiber bundles which would be used for the fabrication of the composite material might impose restrictions upon the implementation of the fabrication method. It was therefore important that we set a limit upon the number of fibers which would be allowed for.

Note that an estimate for the required number of fiber bundles could be found from the range of sizes for the fiber bundles and the eventual maximum size of the products to be fabricated. If the smallest fibers are used in a flat panel twelve feet wide, approximately 48,000 fibers would be required for a single layer. If the largest fibers were used, approximately 2800 fibers would be needed. These estimates are based upon a single, woven layer of material with all of the fibers touching. This would tend to give a larger number of fibers than would actually be needed.

For the twelve inch square geometry, the minimum and maximum fiber sizes yield 64,000,000 and 230,000 fiber bundles respectively for a rectangular array of closest packed fiber bundles which are all oriented in a longitudinal direction. Again, it is unrealistic to assume that a closest packed arrangement could be achieved, so that this estimate is probably quite larger than what is actually required. Because of the many factors which can influence the required number of fibers, and the probability that a solid twelve inch square cross-section of only longitudinal fibers will seldom be needed, it was decided to base our target specification on the number of fiber bundles upon other factors.

First, we examined what was currently available in the textile industry. We found that many weaving looms which independently control all of the warps using a jaquard mechanism have been developed with as many as 1500 individually controlled warps. Taking this into account, we also understood that in many cases, not all of the fiber bundles which would be combined into a composite structure would have to be actively controlled. We decided that as many as 2000 fiber bundles might be used to fabricate a composite structure.

Angled Fiber Orientation

This specification required the examination of both the purpose and the cause of angled fibers in a composite structure. Usually,

angled fibers are used to carry the principle shear stresses induced in flat panels and similarly shaped parts. Conceivably, a composite part which can be stressed from many different points might use these angled fibers to carry the normal stresses as well. Perhaps as the development of composite materials continues, parts can be make with fibers oriented only in the directions of greatest stress so that weight can be saved. For a complex composite part, the principle stress directions may vary significantly throughout the part. It would therefore be advantageous to allow for the placement of fibers in any direction within the structure.

The actual direction that a fiber might take as it traverses a composite structure is governed by the fact that it can only pass through spaces in between the other fibers. For this reason, it is useful to consider the direction of the fiber in terms of passing through a rectangular grid of other fibers. This is especially true when considering the bias fibers used in weaving and semi-weaving or the angled fibers in semi-braiding. This consideration limits the number of possible orientations of the angled fibers to a finite number, but still a large number of possibilities. It also suggests that the means by which the angled fibers can be positioned could involve the non-angled fibers as well. This will be discussed in greater detail as needed.

As a result, we found no reason why the orientation of any of the angled fibers should specifically be limited. There is a likelihood that any orientation would have advantages in some application, and no orientation would be impossible to closely approximate.

Amount of Through-the-Thickness Fibers

In our discussions with NASA, the reasons for having through-the-thickness fibers were emphasized. Having fibers which are oriented through the thickness of the composite structure help to

improve the toughness, or damage tolerance of the structure. For some applications, these fibers are only needed to bind the other fibers together, such as in the semi-weaving pattern discussed earlier.

We determined that in weaving and semi-weaving processes, it would be advantageous to allow as many as ten percent of the fibers to be used for through-the-thickness orientations. Any amount of fibers up to this percentage could be used, depending upon the application. For the semi-braiding and braiding patterns, the through-the-thickness fiber orientations have the same meaning as the angled fiber orientations, so that this limitation does not apply.

Fiber Tension Variation

During the course of our research, we found that the tension in the fibers used to fabricate textile products was important for several reasons. First, and most obvious, is to maintain control over the position of the fibers as they are being maneuvered into position within the product. Also, the tension of the individual fibers helps to control the positioning of the final product, as in weaving operations. In braiding operations, the fiber tension prevents entanglement of the fibers as they cross, as well as helping to insure that the braided product is tightly packed together.

Conceivably, the fiber tension could be used to control the actual shape of the product being manufactured. For example, the tension on one side of the object could be larger than on the other side during manufacturing so that the product bends as it is made. This could eliminate residual stresses in a product which must be bent anyway.

From the standpoint of machine design, it was decided that ten pounds would be a reasonable maximum tension to be placed in any one fiber. If 2000 fibers were used at this tension, that would result in 20,000 pounds of tension, which is somewhat unrealistic. However, limiting the tension in the fibers does not necessarily imply that all

2000 fibers must undergo this tension. This could be the maximum used for varying the tensions in the fibers. In conventional weaving and braiding practice, significantly lower tensions are used.

Speed of Production

This specification is the probably the least important of the list. That is because in the aerospace industry, production runs are not so large that rapid production is required. Also, the costs for materials and labor are often the determining factors in the aerospace industry. In our communications with NASA, we were repeatedly informed that the production speed was not significant. An example of the insignificance of production speed is the braiding of some rocket nozzles. These nozzles are braided, by hand, around a mandrel, an operation which can take several weeks for each nozzle.

This does not mean that we do not need a target specification concerning the speed of production, however. During our research we found that some of the existing concepts for braiding three-dimensional structures were capable of producing at speeds of three inches per hour or more. Usually, the processes involved were capable of much faster speeds, but not always. We decided that this would be a reasonable lower limit to the production speed for such products.

Summary

The target specifications that have been presented here can be considered the minimum requirements for the successful fabrication of a three-dimensional composite structure. The specifications concern the requirements of the product only. They are summarized in Table 4.

Table 4

1. damage tolerance of the fibers used to make the product:
   - minimum bending radius: 0.05 inches.
2. the diameter of the fibers used to make the product:
   - from 0.0015 inches to 0.025 inches.
3. size of the object to be made:
   a. in the prototype stages, twelve inches wide or four inches square.
   b. in the final stages, twelve feet wide or twelve inches square.
4. the number of fiber bundles to be used for making the product:
   - as many as 2000 fiber bundles.
5. fiber angle variation:
   a. for weaving and semi-weaving, any angle between longitudinal fibers and transverse fibers.
   b. has no meaning for semi-braiding and braiding.
6. amount of through-the-thickness fibers in the product:
   a. for weaving and semi-weaving, as much as ten percent.
   b. has no meaning for semi-braiding and braiding.
7. fiber tension variation:
   - between zero and ten pounds for each fiber.
8. speed of production:
   - at least three inches of product per hour.

CHAPTER 5

ALTERNATIVE CONCEPTS

In our communications with NASA, we were informed of a number of existing schemes for the fabrication of three-dimensional textile and composite products. Some of these have been used successfully for textiles in the past. Some of the concepts were recently developed at NASA specifically for application to composite structures. We were allowed to create additional concepts to be evaluated alongside these existing concepts. Several brainstorming sessions resulted in the generation of a list of alternative concepts. These concepts were then used as input to other idea-generating sessions. These sessions resulted in the concepts which will be described in this chapter. They are presented in no particular order, but are divided according to whether they previously existed or not, and whether they are main or support concepts.

Existing Main Concepts

Bluck Braider

The Bluck Braider consists of a series of rotating heads which use pairs of fingers to alternately grasp and release fiber packages which are adjacent to the heads, as shown in Figure 6. The fingers are actuated by the rotation of the heads. The braider can produce a wide variety of three-dimensional shapes with the same braided pattern. This pattern is fixed by the machine and cannot be changed.

Fukuta Braider

This braider is quite similar in operation to the Bluck Braider. It is shown in Figure 7. It also uses rotators to move fiber sources in a fixed pattern.

Two-Step Braider

The Two-Step Braider consists of a series of fiber packages which can be passed diagonally through a grid of fixed longitudinal fibers, as shown in Figure 8. These sources are successively moved in one diagonal direction, and then in the perpendicular diagonal direction. Each time, all of the sources are moved completely across the product. The process repeats itself after the two moves, thus the name Two-Step. This method produces a fixed pattern which depends upon the shape of the product.

King 3-D Loom

The original King 3-D Loom consisted of a set of rigid longitudinal rods which were held in a frame, as shown in Figure 9. A set of needles was used in the other two mutually perpendicular directions to insert fibers between the longitudinal rods. The ends of the inserted fibers were held with pins until enough material had been produced to hold its shape. This method can be used to create billets out of the fibers.

One modification to this process would be to substitute normal longitudinal fibers for the rods used in the original process. Also, a method for shifting the longitudinal fibers (warps) could be used to add flexibility to the method. This is what we considered to be the King 3-D loom concept.

AYPEX

The AYPEX (Adjacent Yarn Package EXchange) scheme is based upon the fact that any system of parallel fibers can be braided into any pattern by performing a series of adjacent fiber exchanges. There are four possible ways in which fibers can be exchanged. This method could be implemented as shown in Figure 10. The fiber packages could be moved from one rotator to another, then they could be exchanged with a 180° rotation of the rotator. One prototype of this machine exists. This machine uses a series of cantilevered hooks which can exchange all of the longitudinal fibers within a row or column. It is not capable of truly arbitrary patterns. This is only a feature of that particular prototype, however, and is not restricted by the concept.

Farley Bias Needles

This concept consists of a series of needles which ar held at the pitch of a woven product, as shown in Figure 11. Each of the needles may be moved independently of the other needles. All of the needles are moved transversely across the product during each cycle. Then, the needles are extended through a layer of the product, passing a loop of the bias fibers through the product. The weft fiber is then inserted to trap the bias fibers in place. The needles are then withdrawn and indexed again. The angle of the bias fibers can be controlled by varying the amount of indexing and the frequency of extending the needles. Bias fibers can be inserted into any layer of a multi-layer semi-woven product using this method.

Farley Braider

This braider consists of an array of rotators. Each rotator consists of a linear bearing, a rack, and some electrical contacts as shown in Figure 12. The fiber sources are contained in self-propelled

tractors which use a stepper motor to drive a pinion which meshes with the rack on each rotator. The tractor rests upon the linear bearings on the rotators. To actuate the braider, a series of the rotators are aligned so that their individual pieces of the linear bearing line up to produce a long linear bearing. The tractor then passes along the bearing, propelled by the pinion on the rack, being powered and controlled through the electrical contacts. To change direction, the tractor must stop on a rotator. Then, the rotator rotates to one of three other positions, aligning itself with other rotators in the new direction. The tractor may then proceed in the new direction. This scheme allows any path to be made through a set of stationary longitudinal fibers to create a semi-braided product. Also, several of these tractors could be used to create a braided pattern.

Magnaweave (Florentine)

The Magnaweave consists of an array of movable fiber packages. These packages may be moved in either of two perpendicular directions within a rectangular grid, as shown in Figure 13. The actuation of this motion is performed by solenoids or cylinders which push upon the packages along the ends of the grid. Each package pushes against its neighbor so that an entire row or column of packages is moved. This allows the packages to be moved in a fixed pattern around the surface of the grid. The pattern produced by this concept is dependent upon the shape of the product.

Existing Support Concepts

Farley Inflatable Boot Beat-up

This concept was devised as a support concept for the Farley Bias Needles concept. That concept required a method for insertion of the

weft (fill) fiber into the space between the warps and bias fibers. Also, it was felt that the presence of the bias fibers would present beat-up difficulties. This concept involves a cantilevered beam which can be inserted between the warps, as shown in Figure 14. This beam would carry the weft fiber across the product. Then, an inflatable boot along the length of the beam would inflate and push the weft fiber into the proper position. The beam could then be withdrawn to allow the other processes to take place for the production of the product.

Jaquard Heald

This device, considered a support concept consists of a series of cords which are independently controlled to move the warp fibers in a conventional weaving operation, as shown in Figure 15. The means by which this independent control is achieved was originally performed with control rods and hooks. These rods were selected by a series of holes punched in cards. Today, many electronically controlled devices exist which can perform the necessary control of the cords. The actual design of this device is beyond the scope of this paper, but since the device is currently being used for a wide variety of textile applications, it could prove to be useful for the manufacture of three-dimensional composite structures.

New Main Concept:

Separating Warp Supplies

Separating Warp Supplies is a concept for obtaining access to the weft area. Two warp supplies and cantilever healds are required as shown in Figure 16. By separating the warp supplies and using cantilever healds the weft area can be accessed from the rear while the healds are in position 1. The weft area would only be accessible in the

conventional manner while the healds are in position 2. If beat-up at every other pick could be used, then the beat-up mechanism and any bias weaving mechanism could be inserted from behind while the healds are in position 1. If beat-up at every pick were necessary then it would have to be accomplished by another method.

Pivot Braider

The Pivot Braider is a concept for semi-braiding or braiding which can control the path of a braiding fiber relative to the stationary fibers. This braider would have stationary fibers fed through tubes which can pivot in two perpendicular planes, as shown in Figure 17. The point of rotation of each fiber tube is located at the intersection of these two planes and below the plane of the braider bed. The individual fiber tubes could be pivoted so that a bobbin or similar fiber source could be passed between the tubes, creating the desired pattern.

Warp Switcher

The Warp Switcher is a concept for producing woven sheets with bias fibers. This idea uses three sets of warps as shown in Figure 18. Two of these warp sets are for the bias fibers. The third set is for the conventional warp fibers. The conventional warp fibers will need to be supplied by separated warp supplies and changed by using cantilever healds or a similar arrangement that leaves the weft area open. The other two bias warps should have the capability to align with the conventional warps so that the conventional warps can be switched without capturing the bias warp fibers. The bias warps should also be able to transfer bias warp supplies to each other. With these capabilities the mechanism would be able to produce a bias woven sheet. The first step in the weaving process would be to align the bias warps with the conventional warps and then switch the conventional warps. A weft fiber could then be inserted and the conventional warps switched

back to their original position. Once the conventional warps are open the bias warps could preform a warp supply switch. The outside warp supply of each bias holder would be switched to the inside of the opposite holder. The warp supplies on each bias holder would then be moved outward one position. A weft fiber could be inserted to trap the bias fibers into position, and the process could then be repeated.

Tri-axial (Doweave)

The Tri-axial weave, or Doweave, has been used for several years for the manufacture of tear-resistant fabrics. The concept relies on having three uniformly oriented fiber axes instead of two, as shown in Figure 19. One major advantage of this geometry is a more even distribution of the stresses within the structure. Unfortunately, the large holes within the weave cause large resin-rich pockets to form within the structure when used as a composite. These pockets make the structure weak and brittle. An idea to overcome the problems of resin rich pockets in tri-axially woven fabrics is to use the hexagonal holes in this fabric as a path for through the thickness fibers. By using these areas for through the thickness fibers the resin rich pockets are eliminated and the damage tolerance of the final product is increased.

Bias Weaving Belt

A Bias Weaving Belt could be used to weave bias fibers into a single layered product as shown in Figure 20. This belt would surround the product at the weaving line. The part of the belt over the product would rest on linear bearings. Fiber sources located along the belt supply fiber to inserter fingers. Note that several inserter fingers could be supplied by a single fiber source. The inserter fingers have a pivot point on the belt which allows the ends of the fingers to be inserted through the unwoven warp fibers. The bias fiber running from the weave line to the end of the inserter finger forms a shed through

which a weft fiber can be inserted. Once the weft is in place the inserter fingers are withdrawn capturing the weft. This leaves the shed area clear so that beat-up can be done with reeds as in conventional looms. The belt encircles the product so that a bias fiber that starts on the upper edge of the product will go to the other edge along the top of the product and then return across the bottom of the product, producing bias in two directions.

Concentric Ring Braider

A radial braiding arrangement could be accomplished by using concentric carrier rings. Between any two of these carrier rings there are stationary locations for fiber sources, as shown in Figure 21. A carrying device on each ring has the ability to remove a fiber source from a stationary position. The carrier ring is then rotated carrying then removed fiber source to a new location. At this new position a carrying device can do one of two things. It can either place the fiber source in one of the stationary positions on either side of the ring, or it can pass the fiber source to another carrying device on another ring. Stationary fiber sources could be located in the corners of the stationary positions. This combination of capabilities would allow the radial braider to move a fiber source through any path relative to the stationary fibers.

Bias Weave Hook Pass

The Bias Weave Hook Pass consists of two or more sets of hooks which are spaced at the pitch of the woven sheet of fibers, as shown in Figure 22. One set would be on each side of the sheet. The hooks could be used to alternately hold the bias fiber sources which would be woven into the sheet. After the end of one cycle, the hooks holding the bias fibers would index in the transverse direction to provide the correct orientation of the fibers and then move through the warps. The other

set of hooks could then hold the sources until passing the bias fibers back through the sheet.

Bias Insertion Needles

The Bias Insertion Needles concept is a concept which can replace the conventional healds with inserter needles. There are two types of inserter needles used. The first type, called rigid inserter needles consist of a flat bar with slender tubs attached along the bar as shown in Figure 23. Each tube has a warp fiber passing through it. Two rigid inserter needles would be used to produce simple weave with no bias fibers. To change the shed using inserter needles, the needles are rotated relative to one another so that the supply tubes cross as shown in the figure. The second type of inserter needle is call a bias inserter needle. These are similar to the rigid inserter needle except the tubes of the bias inserter needle can move along the bar. The bar has a slot down the center with open areas at the ends. The tubes for the bias inserter needle are attached to small blocks which can slide along the slot in the bar. Each tube and block combination has its own fiber supply. Each one only carries enough fiber to traverse the fabric in the bias direction one time. The blocks with full fiber supplies are inserted in the slot using the open area at one of the bar. The empty blocks are remove from the open area at the opposite end. In order to weave a single layer product with bias fibers in two directions, two rigid inserter needles and two bias inserter needles are necessary. The two bias inserter needles would be placed between the two rigid inserter needles as shown in the figure. The warps can be changed by rotating the bars relative to one another as shown before. The bias angle can be controlled by the frequency of block insertion into the bias inserter bars. Note that a bias inserter needle is necessary for each bias direction desired.

Hex Track

This concept came about as an evolution to the Farley Braider. This concept relies upon rotators, and tractors in a similar fashion. The main difference lies in the fact that the rotators can be used to create a track which has a hexagonal arrangement, as shown in Figure 24. The tractor moves along the bearing or track in the rotators much like for the Farley Braider, except that the change of direction for the tractor may be achieved by changing the shape of the track through rotations of the rotators. The tractor does not need to stop to change directions. Each of the rotators may be rotated to one of three possible positions. This controls the direction for the tractor as it passes over a rotator. Note that at each rotator, there are only two possible choices, right or left. This implies that the braider may be controlled in a binary fashion.

Hex Braider

This concept came about as an evolution of the Hex Track concept. The rotators and tractors are used, as before, except the rotators may now move to as many as six positions, as shown in Figure 25. To facilitate passage of the tractor over a rotator, each rotator has five tracks which converge from five points on the edge of the rotator to one other point on its edge. Those five points are entry points for the tractor, with the remaining point being the exit. Thus, the direction of the tractor is controlled by the orientation of the exit point on the rotator. The tractor can enter any of the fiber entry points depending upon its direction of approach. This geometry allows additional rotators to be inserted into the hexagonal arrangement.

New Support Concepts

Cantilever Healds

The Cantilever Heald concept was developed because of the special needs of some of the main concepts. Many of the concepts required the transverse motion of either the longitudinal fibers or the bias fibers, as well as the normal shedding of the longitudinal fibers for weaving. This necessitated the use of some type of heald which could release the warps periodically, and then push them again to create the shedding action. Figure 26 shows the implementation of this concept. Note that there are quite a few commercially manufactured hooks and needles which might be used for this. Positioning accuracy of this device would be critical.

Cam Beat-up

Cam Beat-up is a concept for beat-up that is accomplish from outside the weft area. A series of thin cam-shaped plates attached along a shaft at the fabric pitch would be used to beat-up the weft fiber as shown in Figure 27. The beat-up would be accomplished by rotating the cams through one revolution, or by rotating through some angle and then reversing. The shaft and cams could be designed to beat-up the weft all at once or to beat-up the weft progressively across the width of the fabric, possibly allowing the insertion of the bias fibers.

Helical Reed

The Helical Reed concept came about as an evolution of the cam beat-up concept. If the individual cam-shaped reeds are staggered at different angles along the shaft, they produce a helix. If the reed is then continuously rotated, the weft is continuously beat into the fell at some point in the structure. The weft could be inserted with a

bobbin so that it is correctly inserted between the warps. Also, some special timing of the warps would be required, such as created by a Jaquard heald. The bias fibers could possibly be inserted more easily in this scheme.

Rib Braider

The Rib Braider is a concept for producing a panel with a braided stiffener which is an integral part of the panel. A braiding mechanism is used to attach a stiffener to the panel, as shown in Figure 28. The braider would be able to manipulate the longitudinal fibers of the panel and incorporate them into the stiffener. The braider would also be able to move in the transverse direction, relative to the panel. This movement would allow the mechanism to produce a stiffener located at ant point on a side of the panel, or create a curved rib. Additional Rib Braiders could be used to make a panel with many stiffeners. However, these stiffeners would not be able to cross unless this capability were incorporated into the design.

Retractable Hooks

A modification of the AYPEX braiding scheme that would improve the flexibility of the process involves using some type of selecting mechanism to determine which fibers are exchanged. One way to accomplish this is to use retractable hooks on the prototype AYPEX braiding mechanism, as shown in Figure 29. Then the hooks for the fibers that are not to be exchanged could be retracted so that they would not hook their fibers. This idea would allow the selective exchange of fibers to yield many more types of braiding patterns.

Noseboard Beat-up

The noseboard of a conventional loom could be used for beat-up if its leading surface were modified as shown in Figure 30. The protrusions on the noseboard could be used to catch the weft and bias fibers lying between the warps. This would be done by moving either the woven produce or the noseboard. This movement would be done once the shed had been changed to capture the weft. Once the weft is caught by the noseboard the produce or noseboard could be moved in the opposite direction to pull the weft tight into the weft. The comb-like edge of the noseboard would allow the shed to be changed after the next weft has been inserted. Careful examination of the shape of the noseboard will have to be made to insure that the bias fibers are not damaged.

Sprung Reed

Beat-up of a weft fiber could be accomplished by using a sprung reed as shown in Figure 31. The sprung reed is similar to a comb that is inserted through the warp fibers. Once in place the sprung reed in moved towards to woven product to push the weft into the structure. The shape of the reeds is designed so that a beat-up on a multi-layer product will exert nearly equal pressure over the product cross-section. Note that the individual fingers of the reed could flex, like a spring, which could then be used to exert a precisely controlled force at every point in the product.

Column Shift

The Column Shift concept was developed as a support concept for the King 3-D Loom. This is a scheme for moving the ends of the warps so that a wide variety of patterns could be produced with the concept. From examination of Figure 32, it can be seen that any path through the warps can be achieved by selectively moving columns (or rows) of the

warp ends and passing a fiber source through the warps. Several passes may be required to achieve complex paths, but any path is possible.

Florentine Heald

This concept borrows from the Magnaweave concept in its operation. The Magnaweave bed could be used as a heald to manipulate the warps in a weaving or semi-weaving process. This would allow the warps to be used for bias fibers as well.

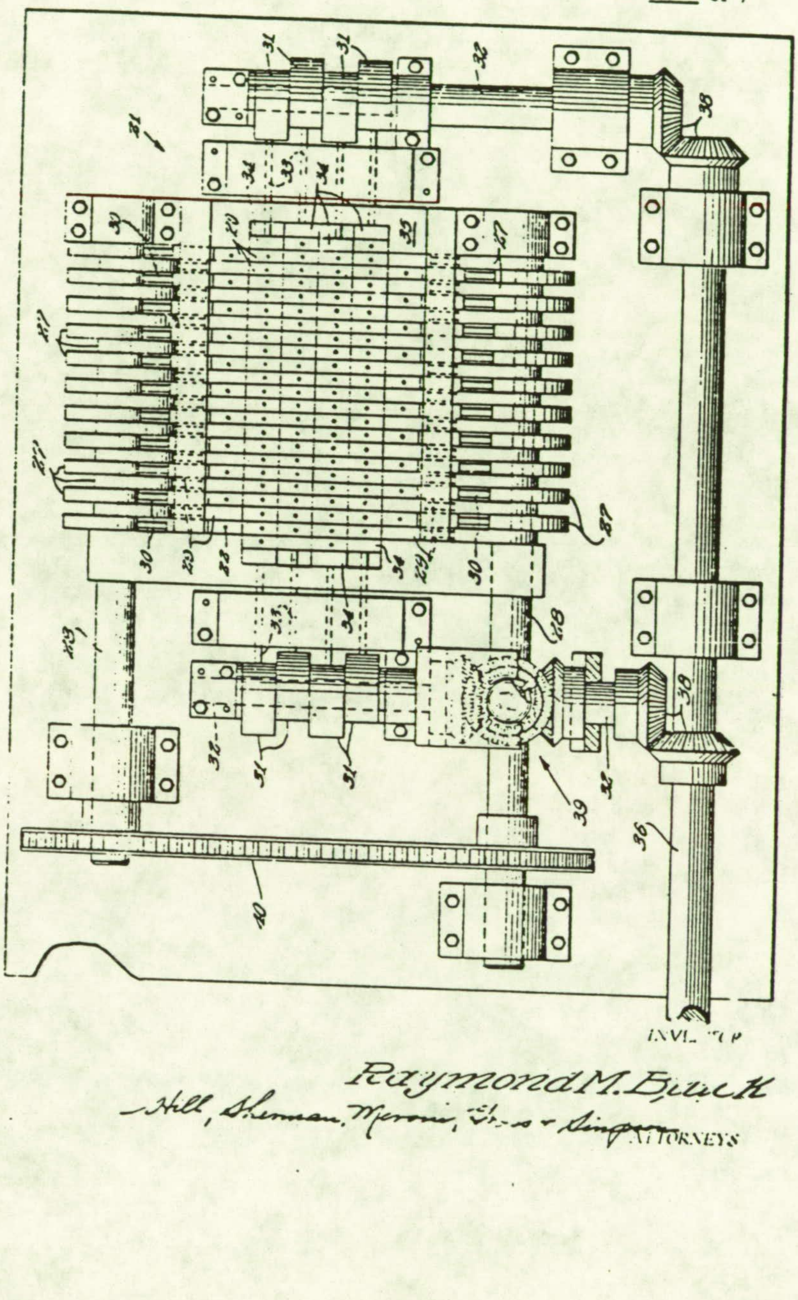
Movable Chain

This concept came about from the need for a method of supporting a set of longitudinal fibers, while having the ability to allow other fibers to pass between them. The Movable Chain consists of a series of chain links attached to each other, end-to-end. Each link is made up of two pieces which can hinge open independently of each other, as shown in Figure 33. To allow fibers to pass through the chain, first, the upper set of link halves is opened. The fibers are admitted into the links of the chain. The upper link halves are then closed. The lower links are next opened, allowing the fibers to pass out of the chain on the other side. Note that any one link may allow a fiber to pass in either direction, but at least one of the halves of each link must be closed, or the chain will fall apart.

Feb. 11, 1969 R. M. BLUCK 3,426,804

HIGH SPEED BIAS WEAVING AND BRAIDING

Filed Dec. 20, 1966 Sheet 1 of 7



INVENTOR

Raymond M. Bluck

Hill, Sherman, Meroni, Gross & Simpson ATTORNEYS

Figure 6. Bluck Braider

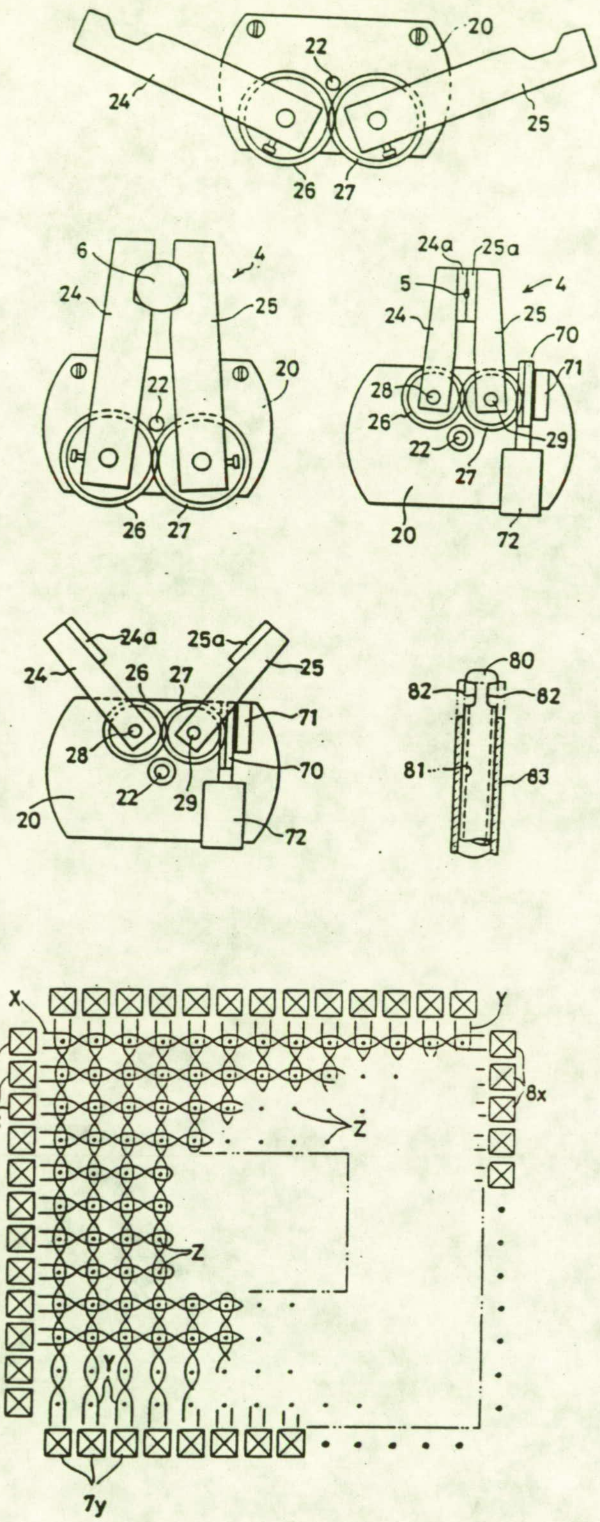


Figure 7. Fukuta Braider

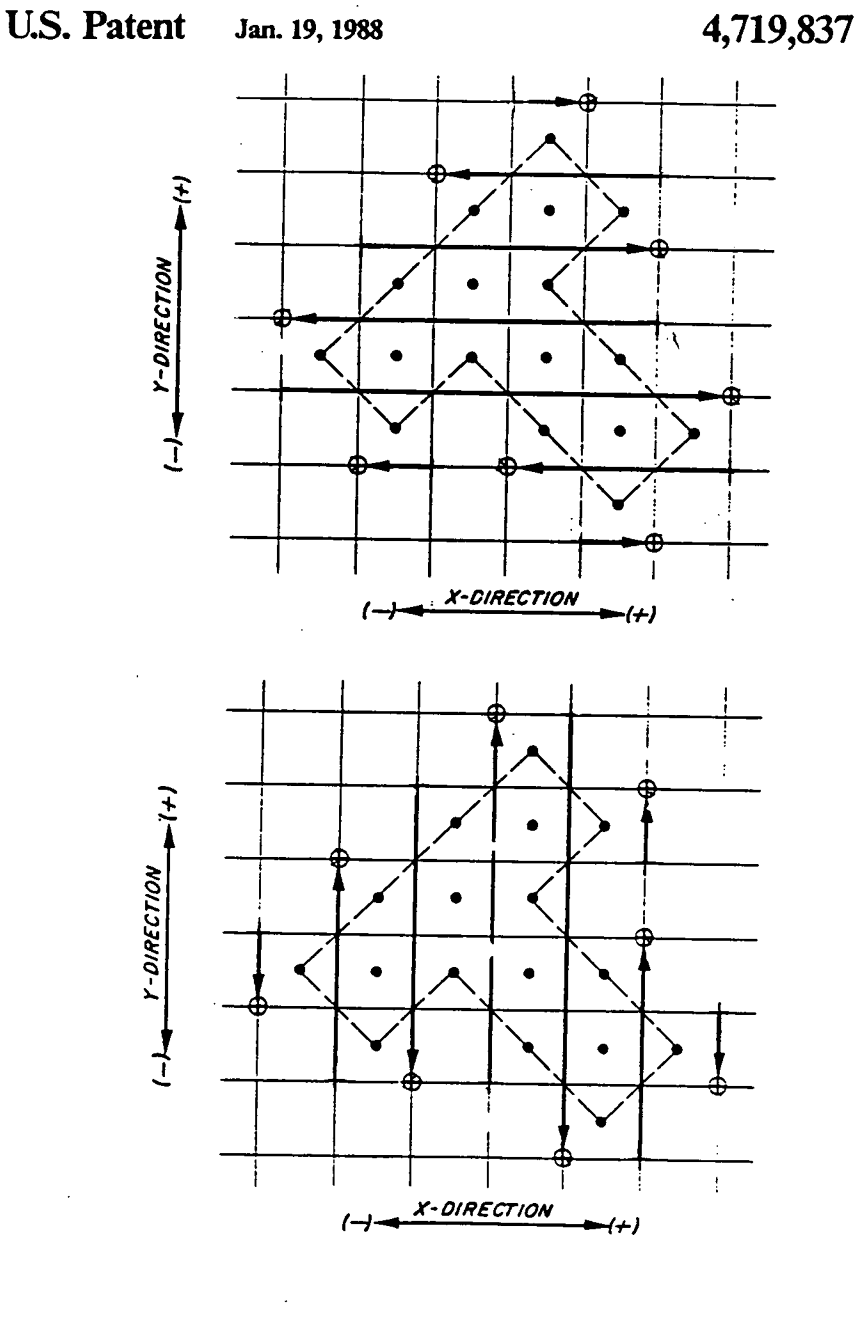


Figure 8. Two-Step Braider

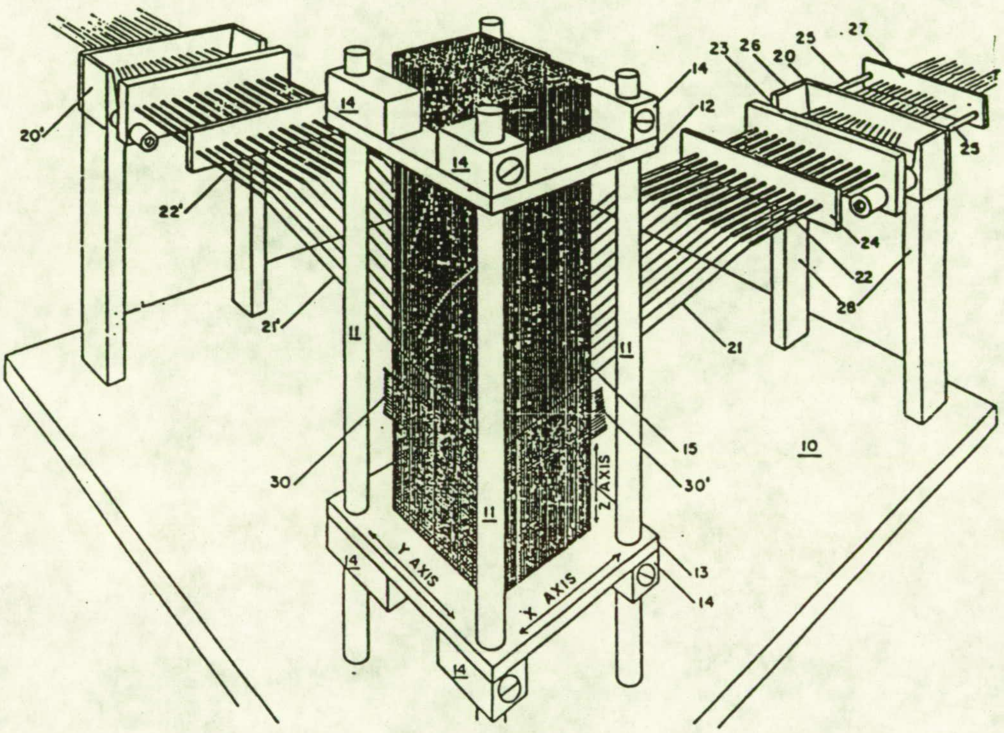


Figure 9. King 3-D Loom

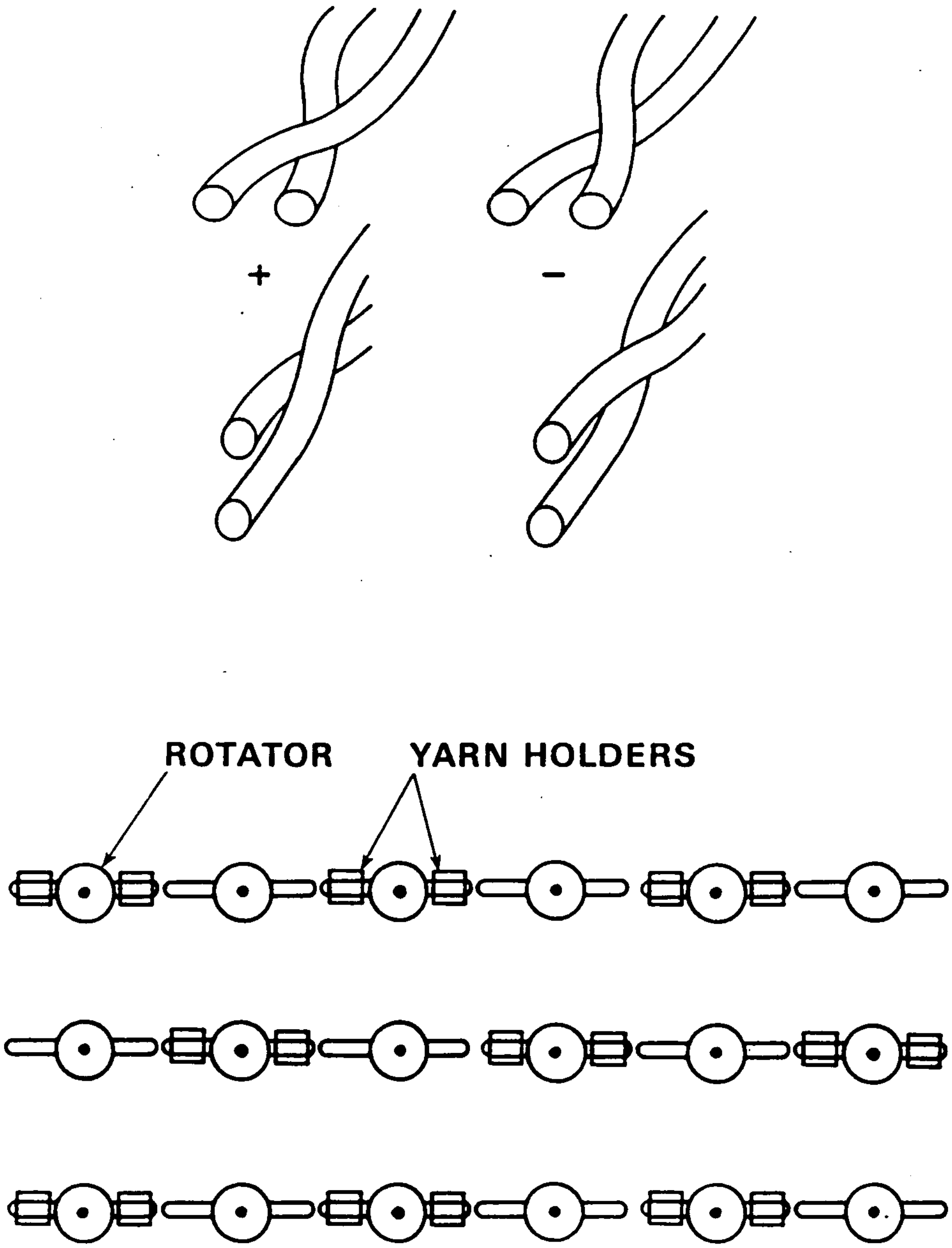


Figure 10. AYPEX

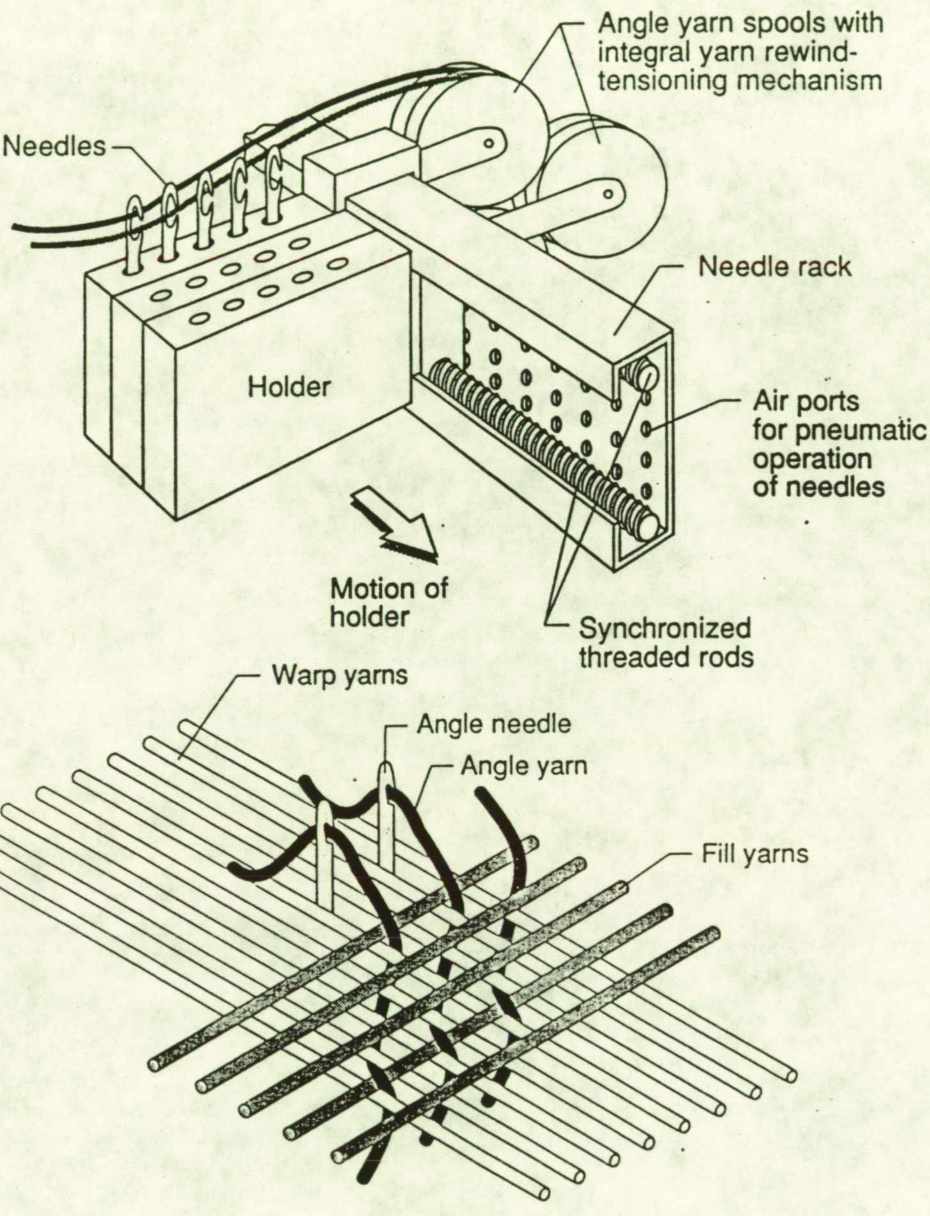


Figure 11. Farley Bias Needles

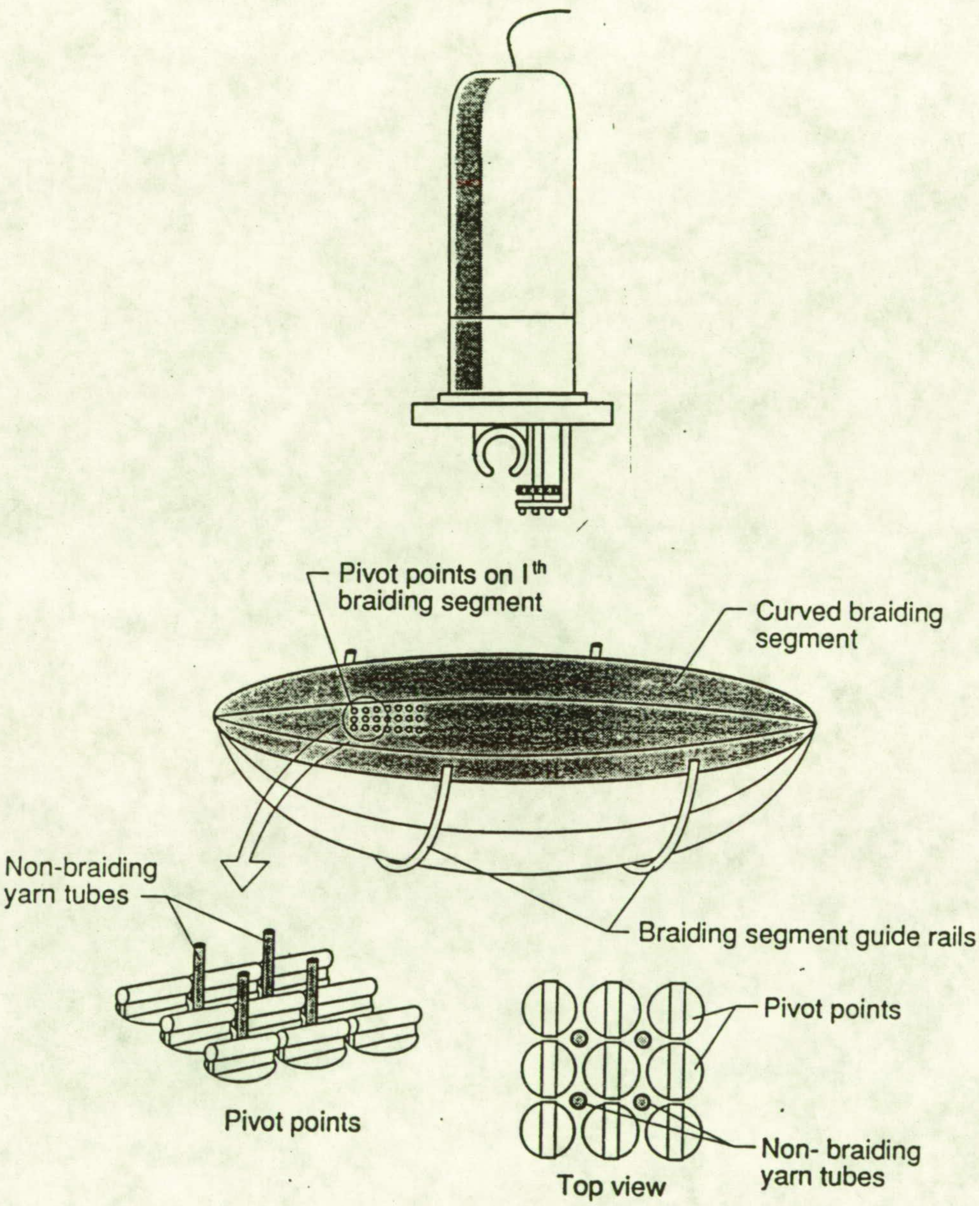


Figure 12. Farley Braider

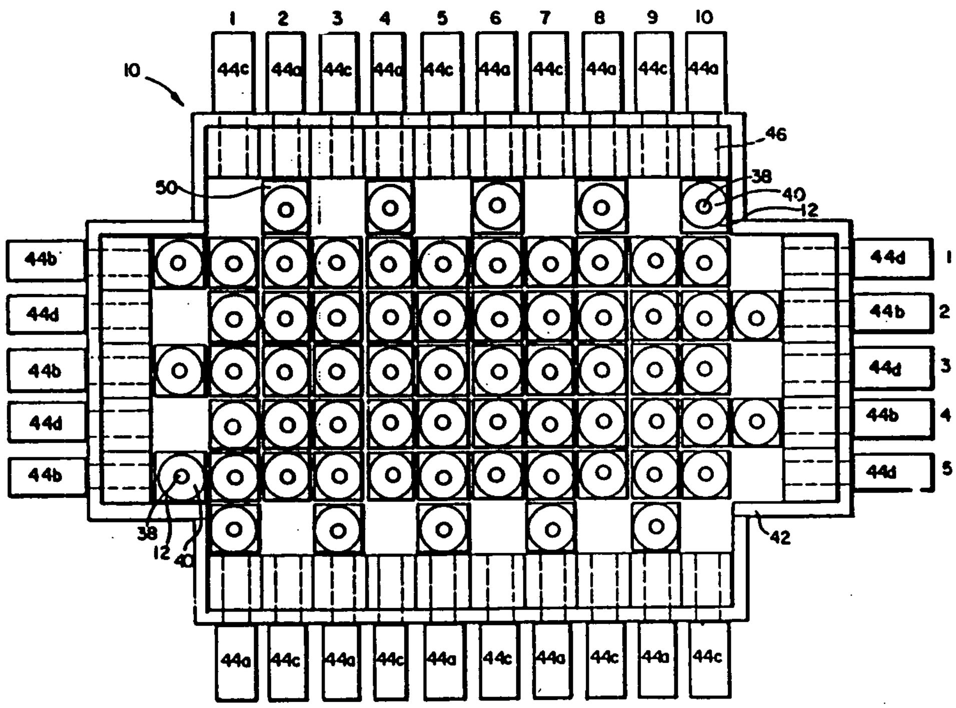


Figure 13. Magnaweave

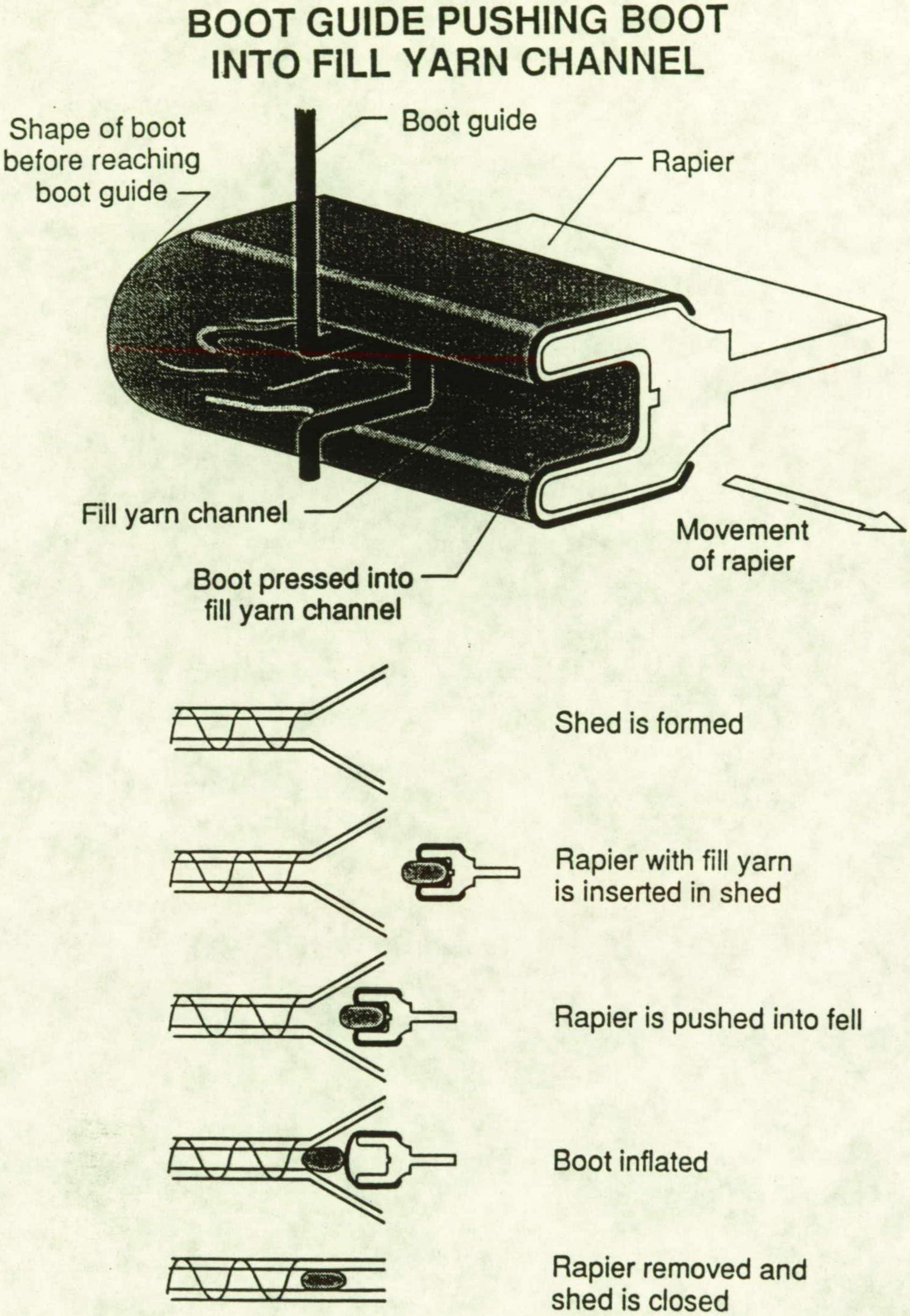


Figure 14. Farley Inflatable Boot Beat-up

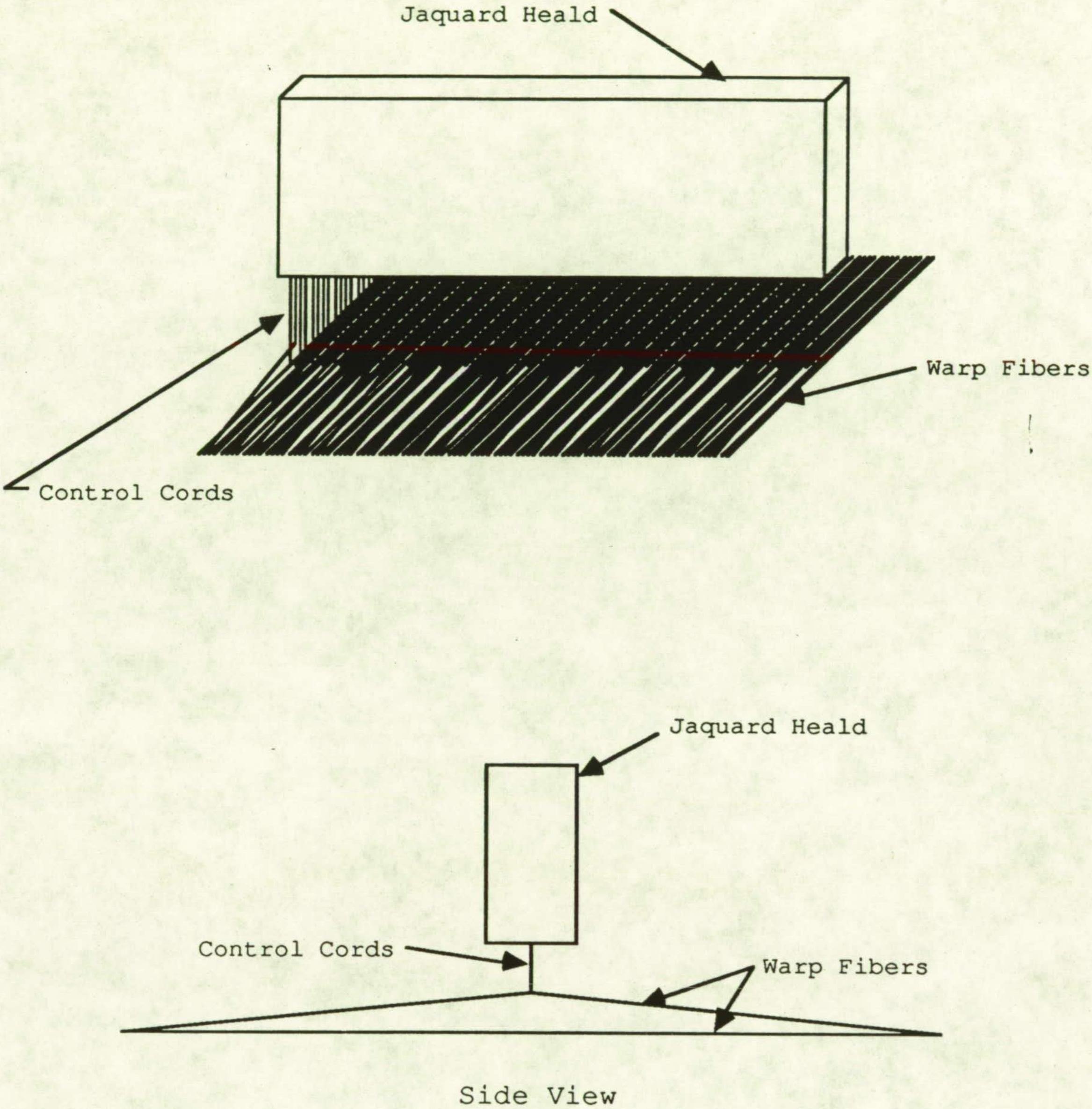
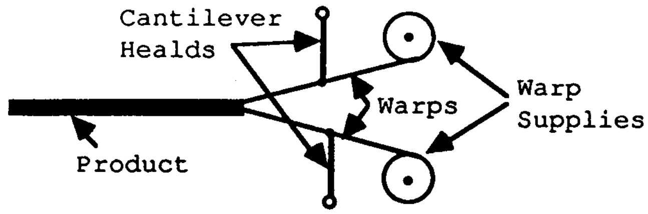
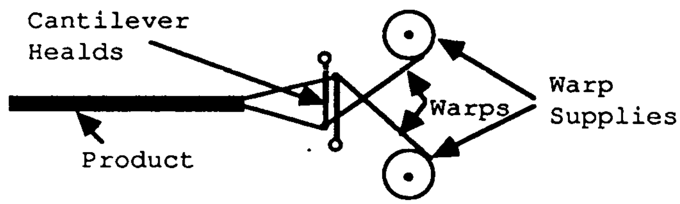


Figure 15. Jaquard Heald



Position 1



Position 2

Figure 16. Separating Warp Supplies

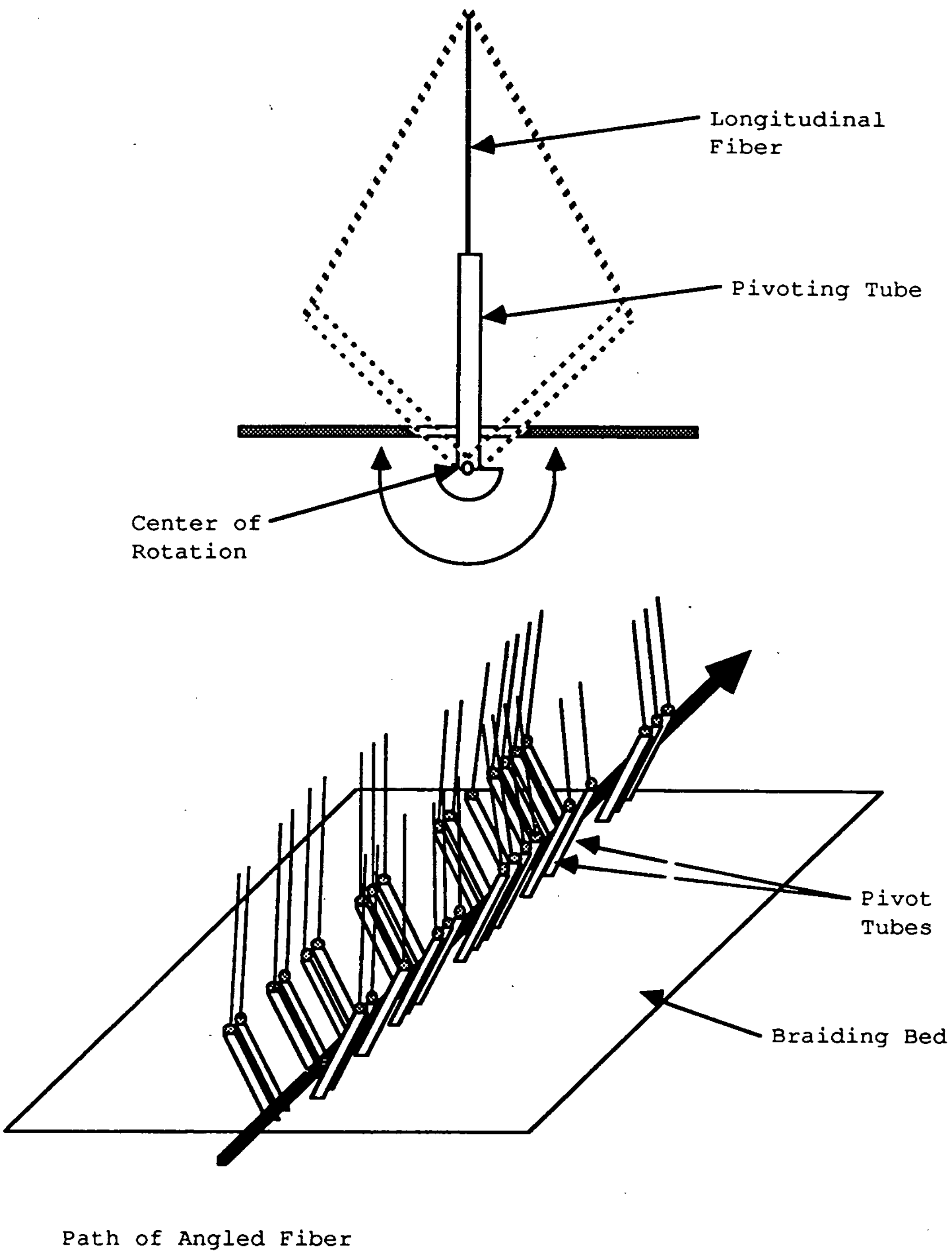


Figure 17. Pivot Braider

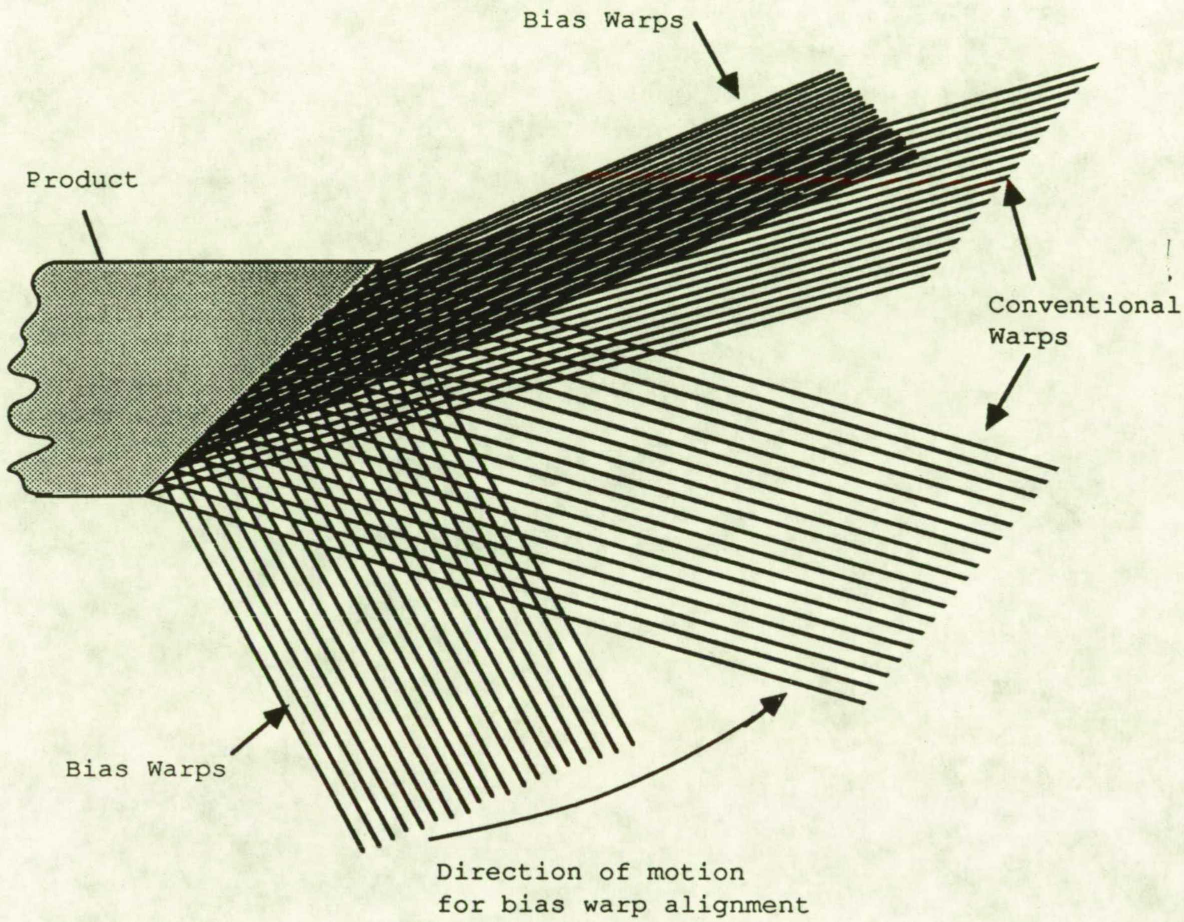


Figure 18. Warp Switcher

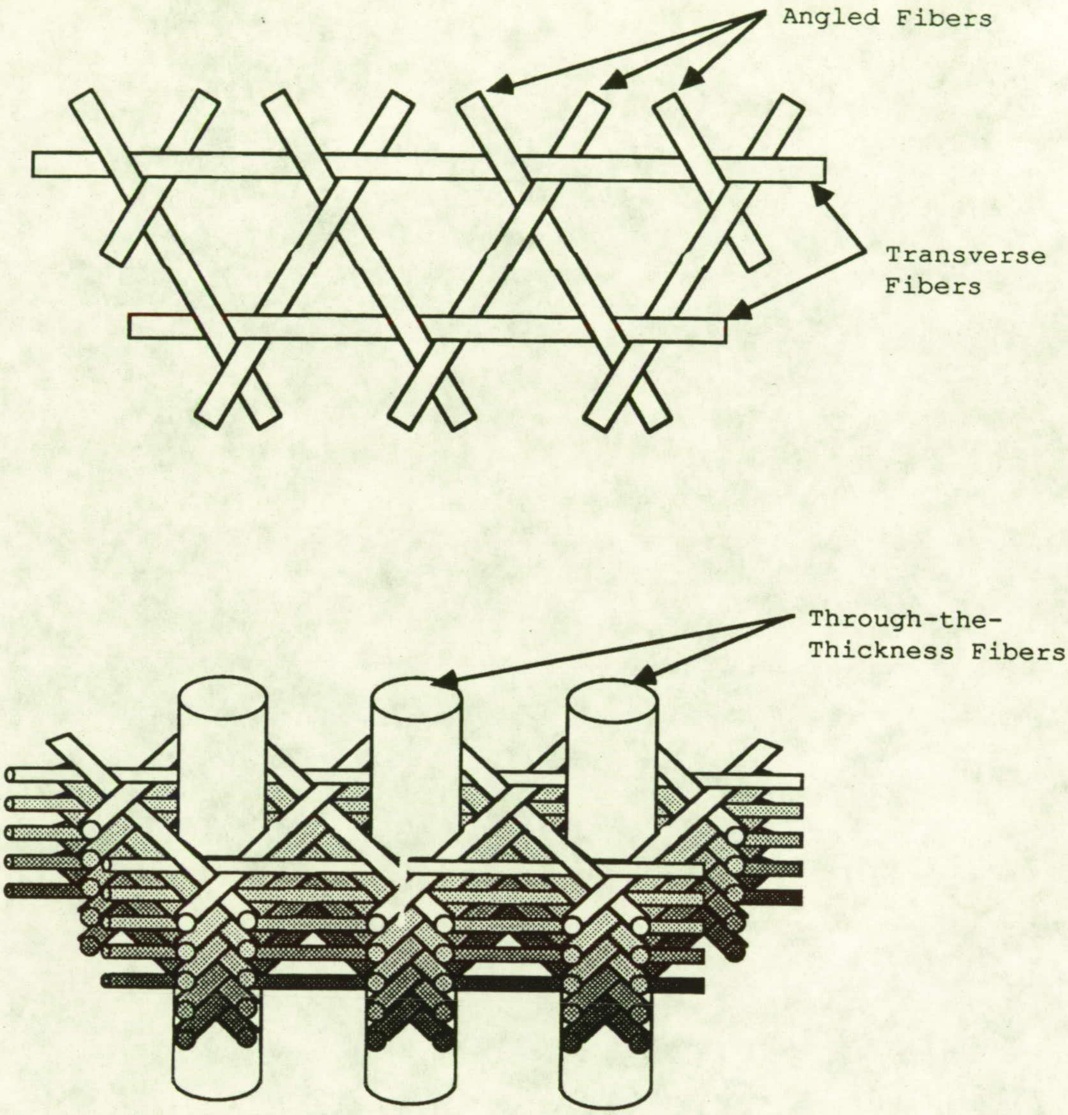


Figure 19. Tri-axial

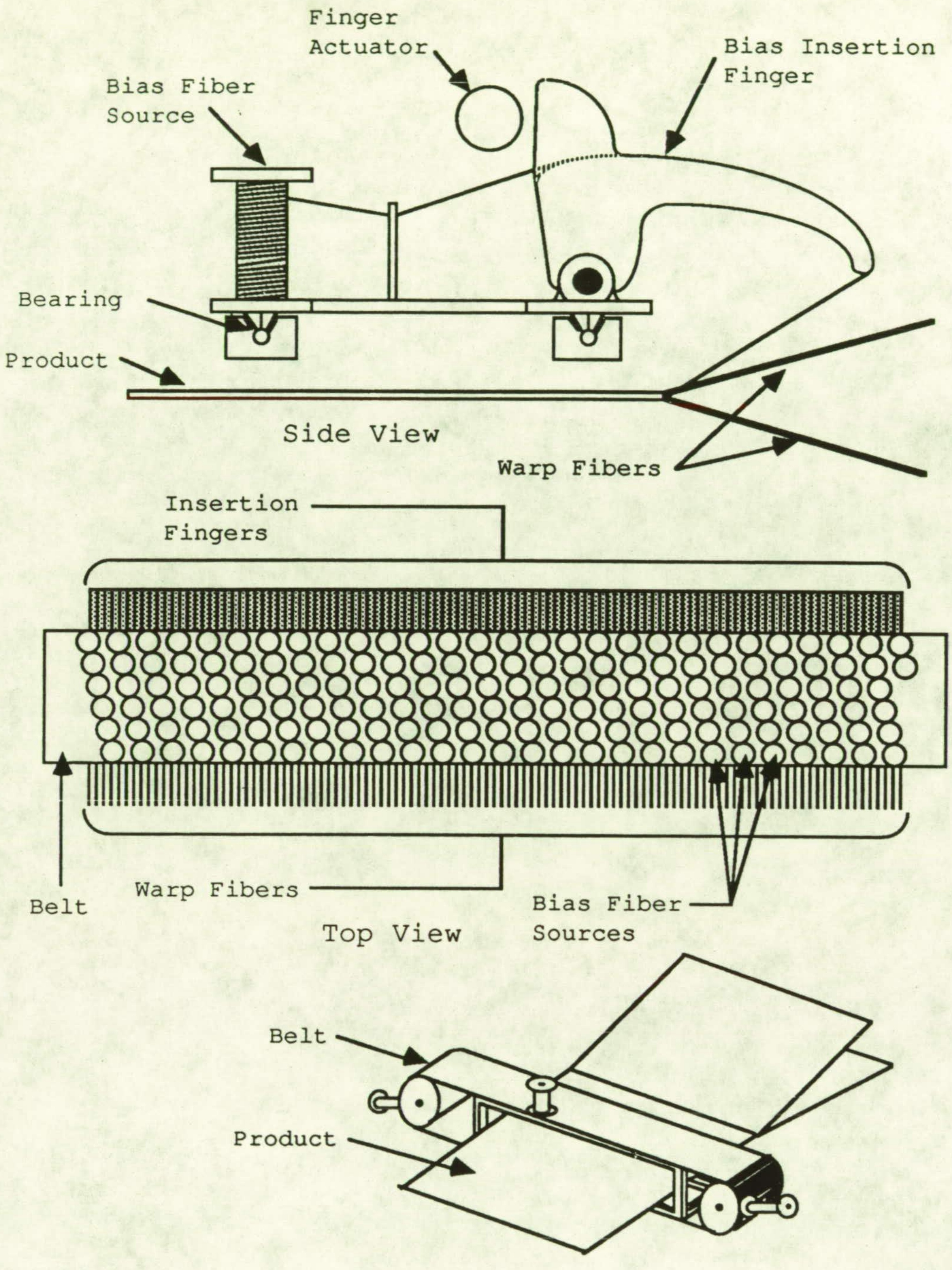


Figure 20. Bias Weaving Belt

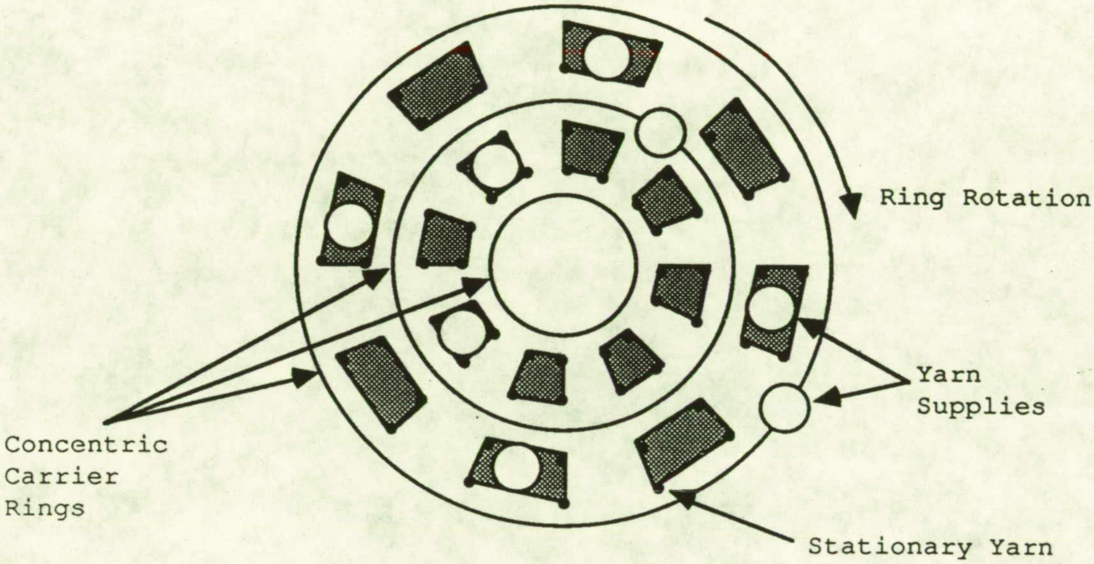


Figure 21. Concentric Ring Braider

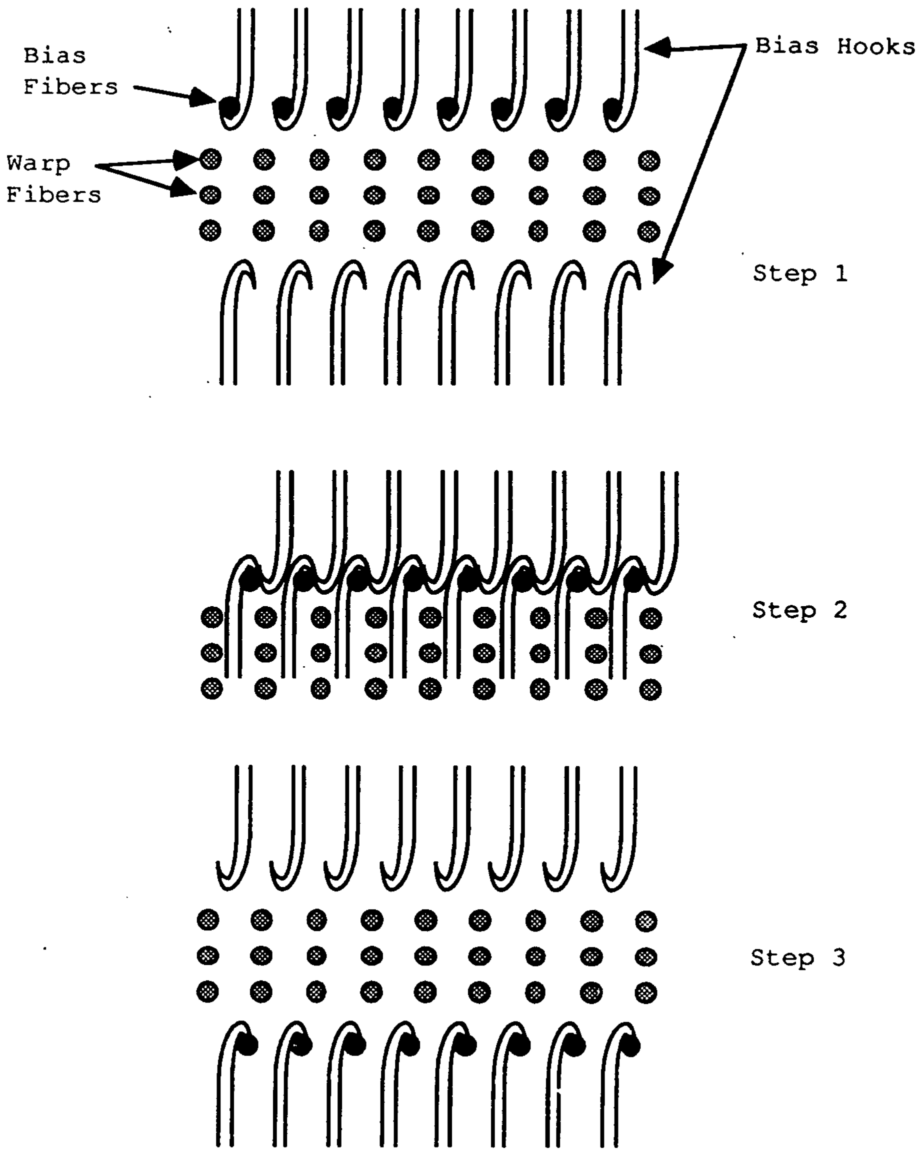


Figure 22. Bias Weave Hook Pass

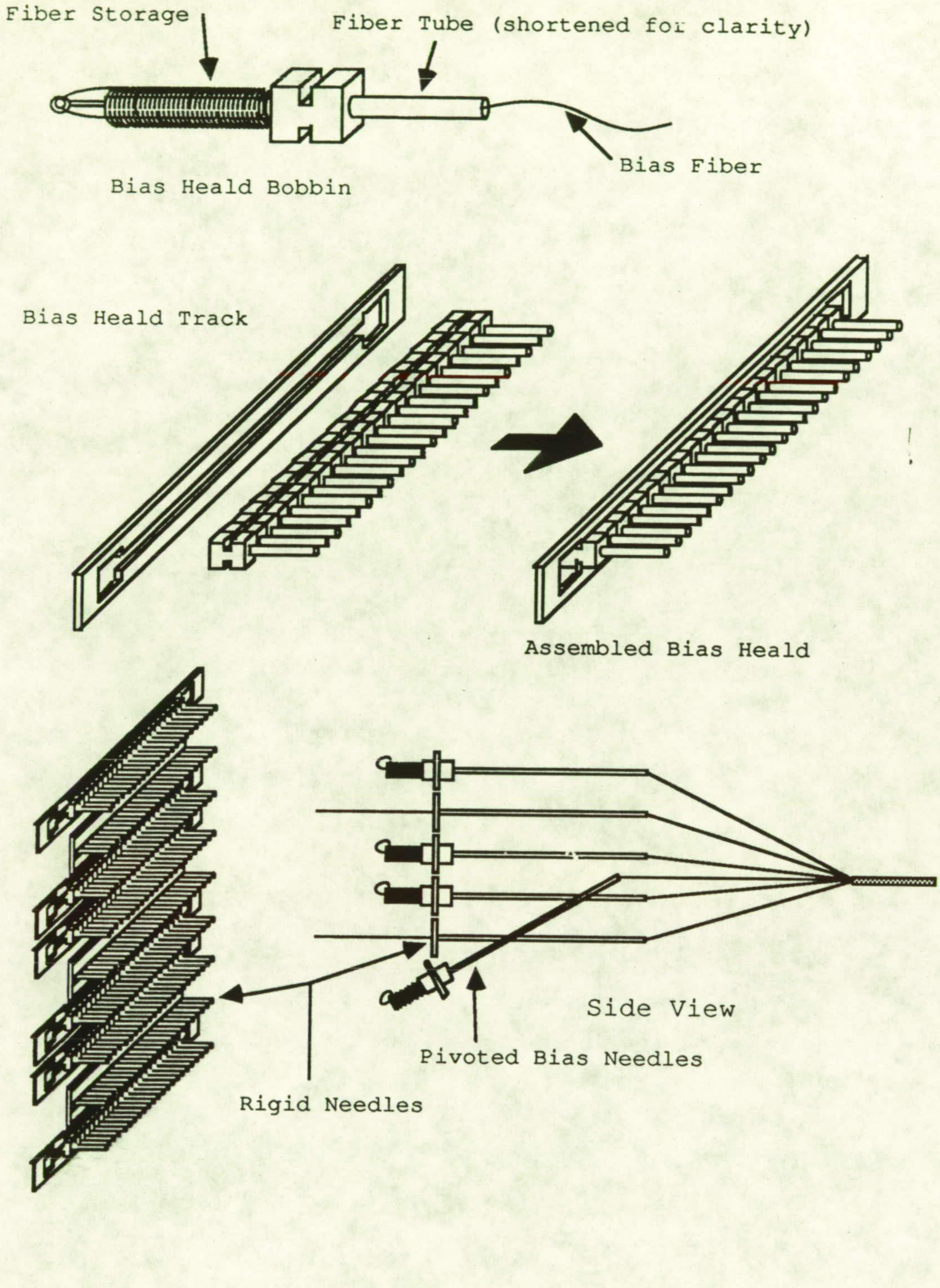


Figure 23. Bias Insertion Needles

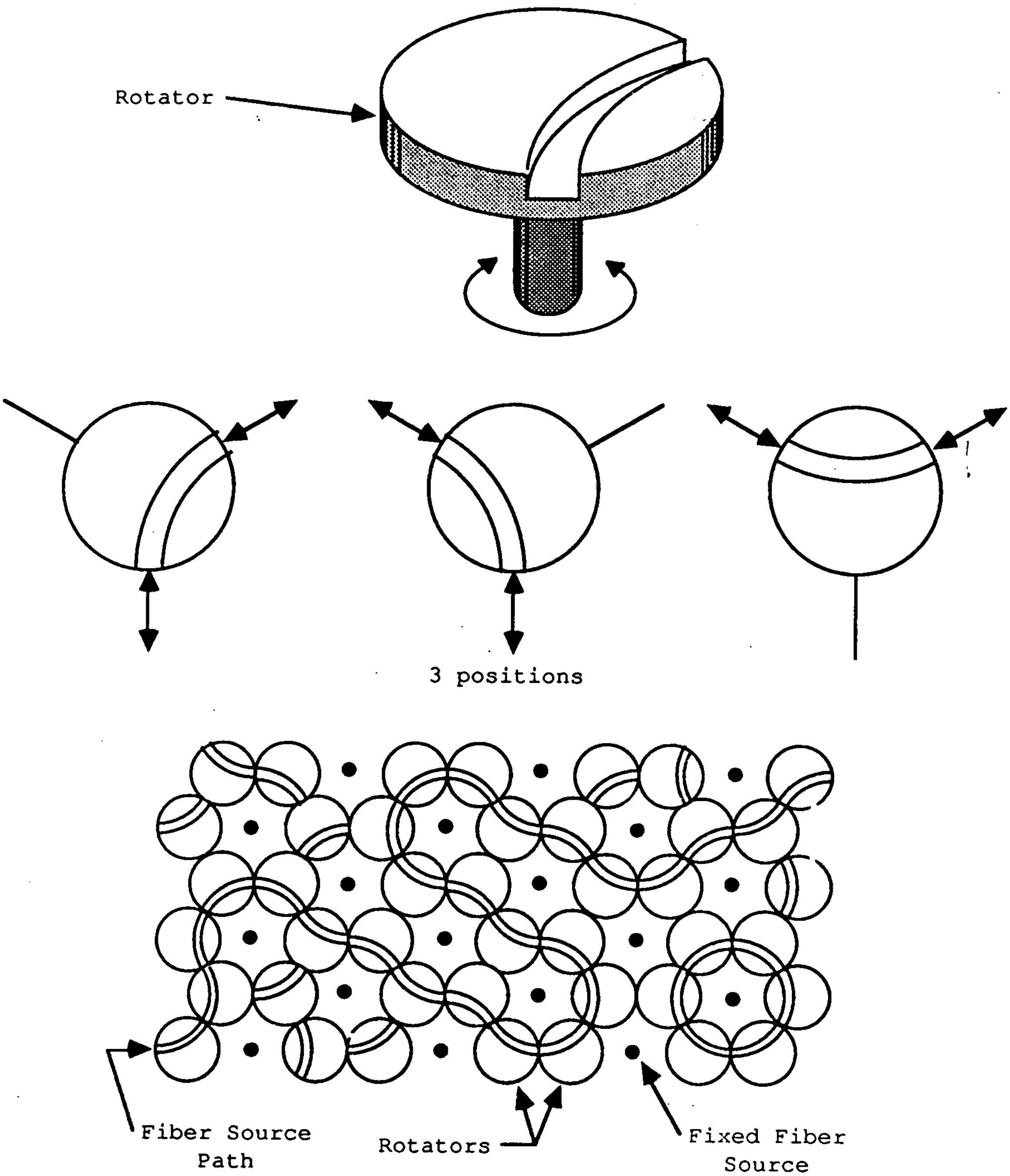


Figure 24. Hex Track

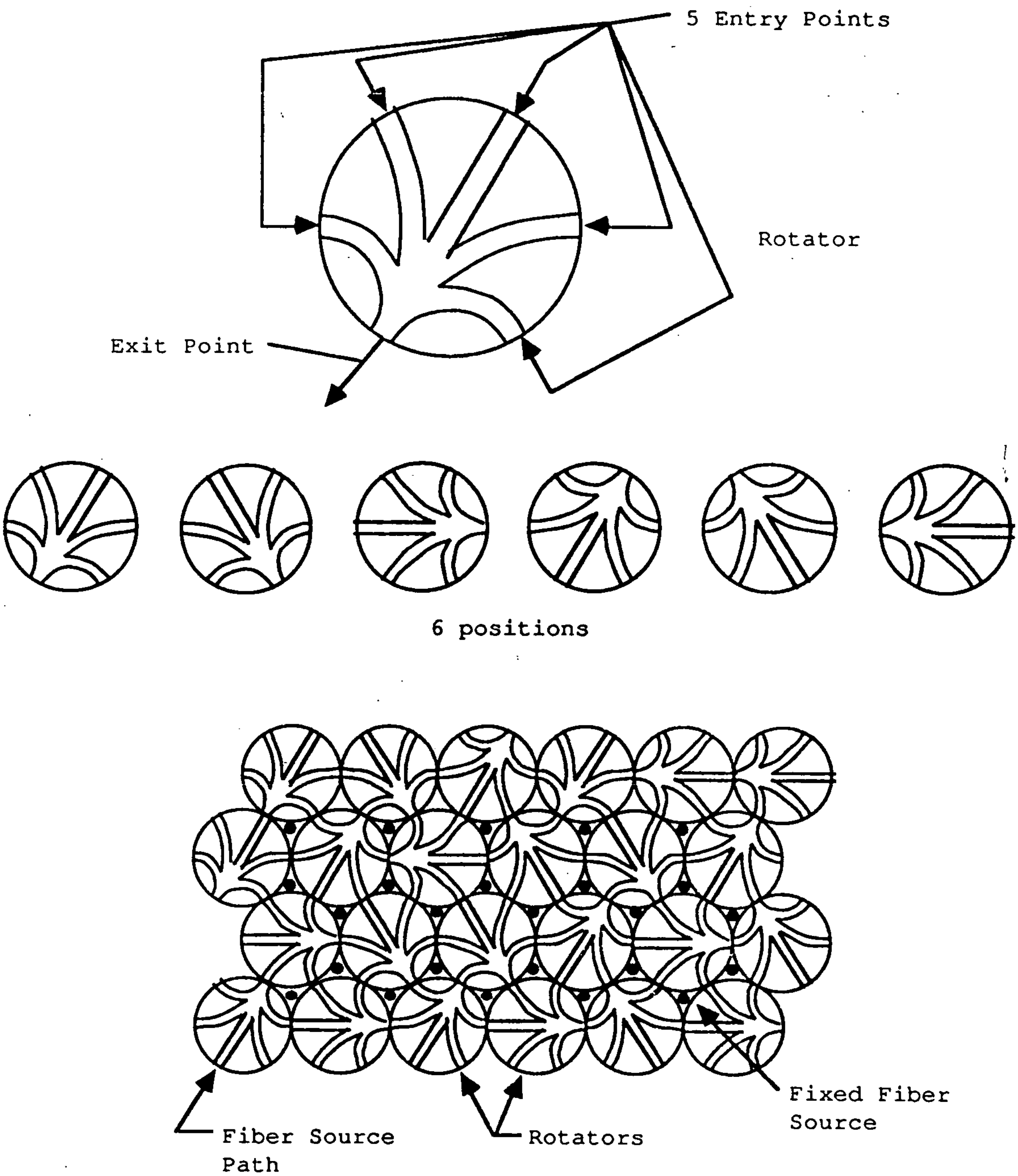


Figure 25. Hex Braider

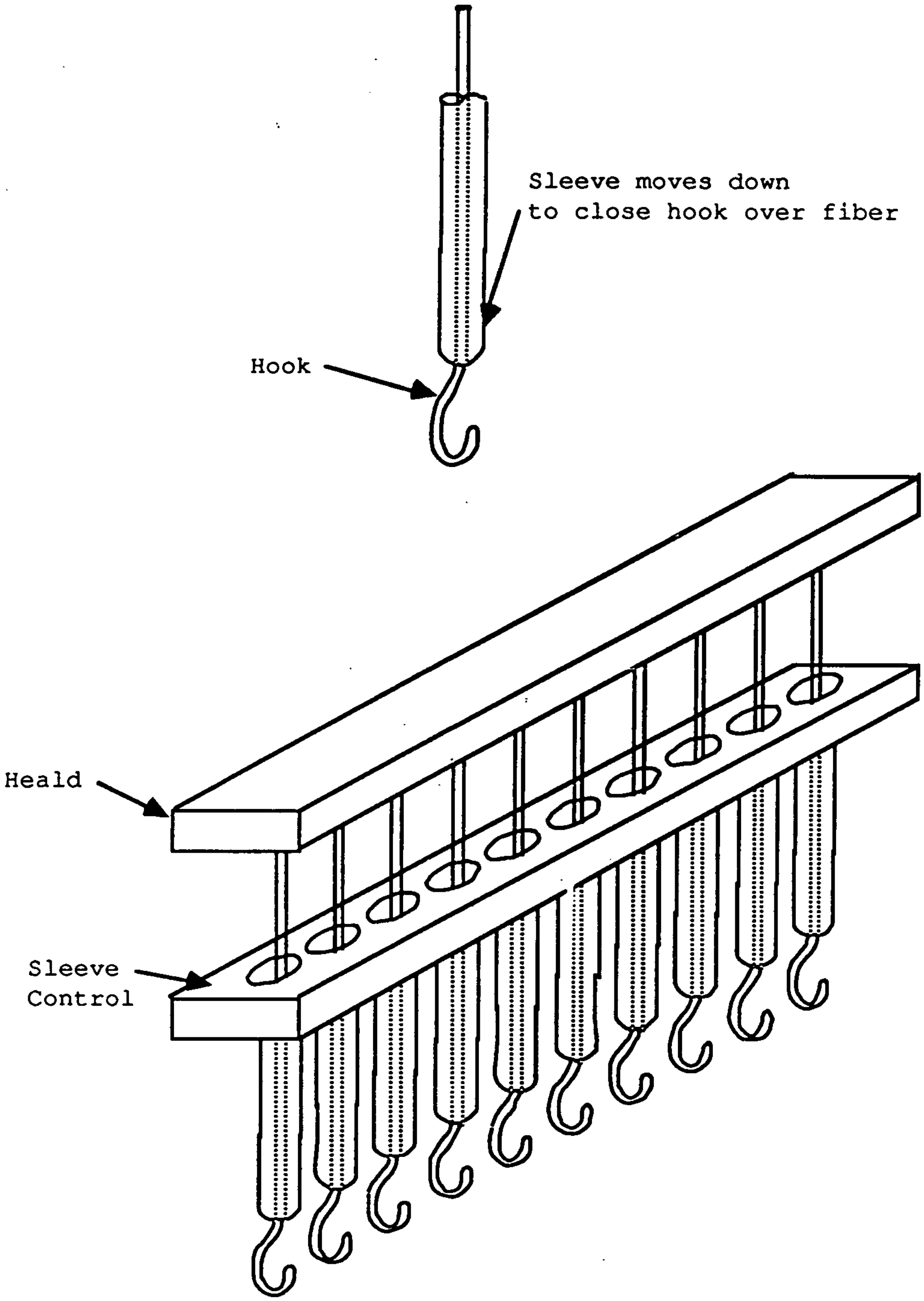


Figure 26. Cantilever Heald

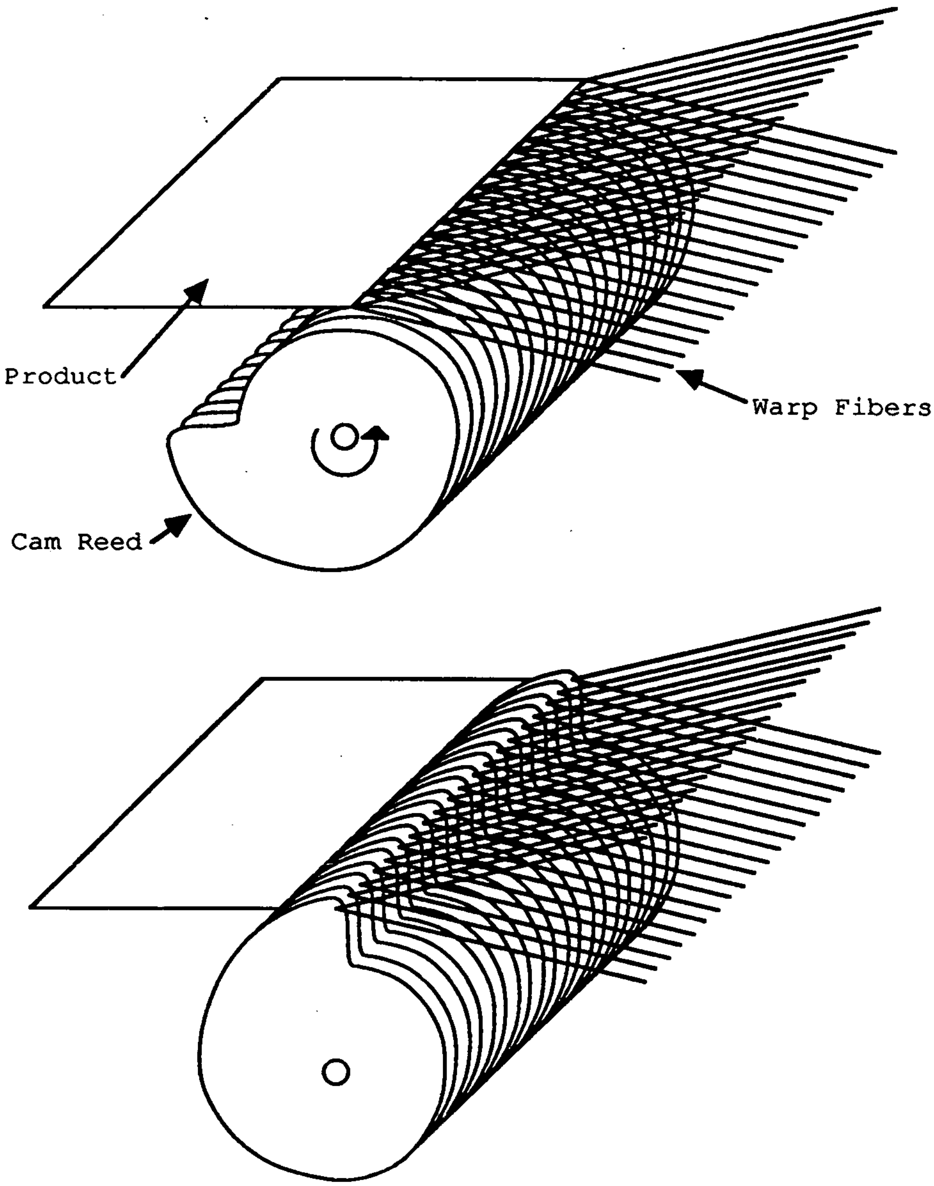


Figure 27. Cam Beat-up

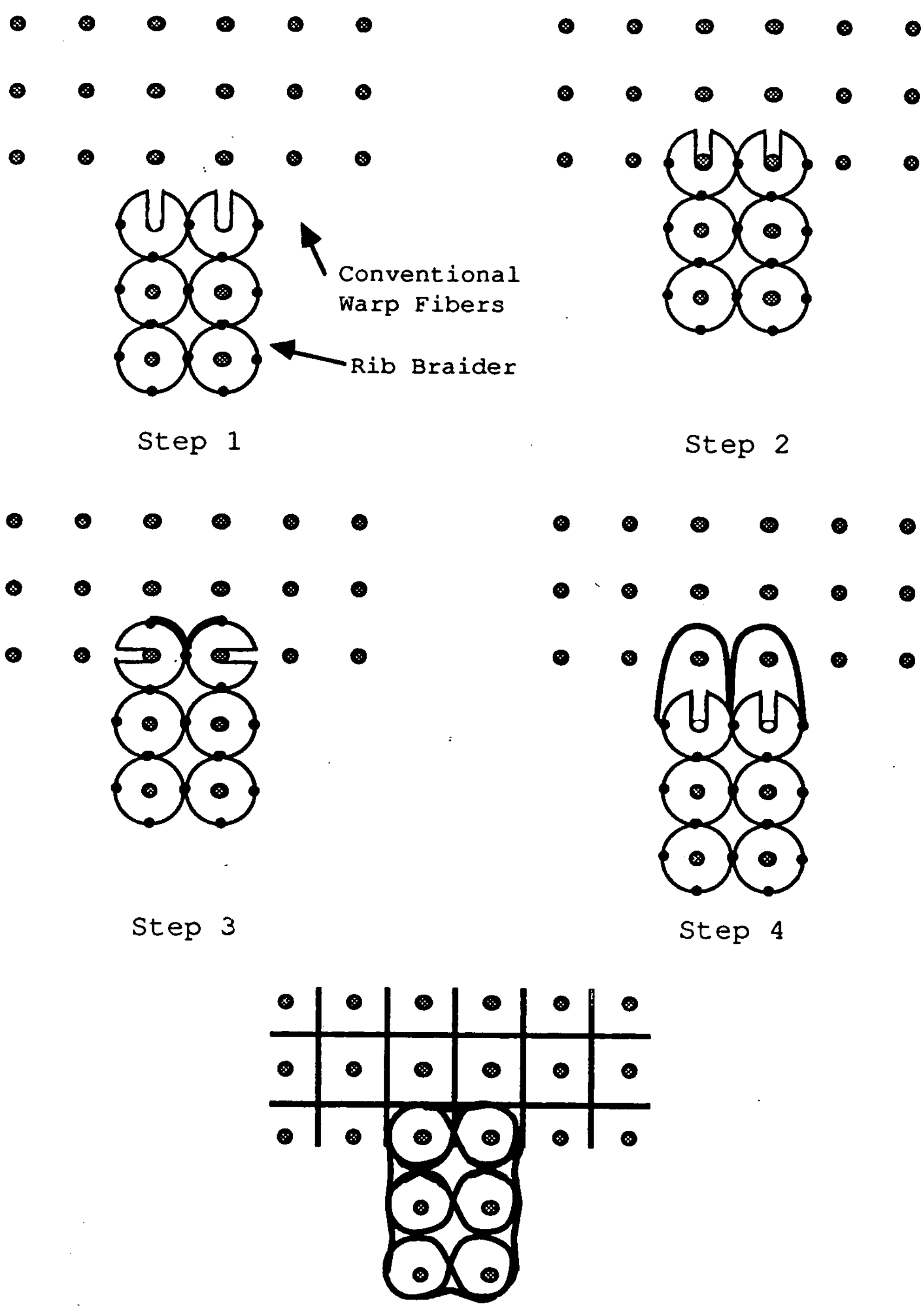


Figure 28. Rib Braider

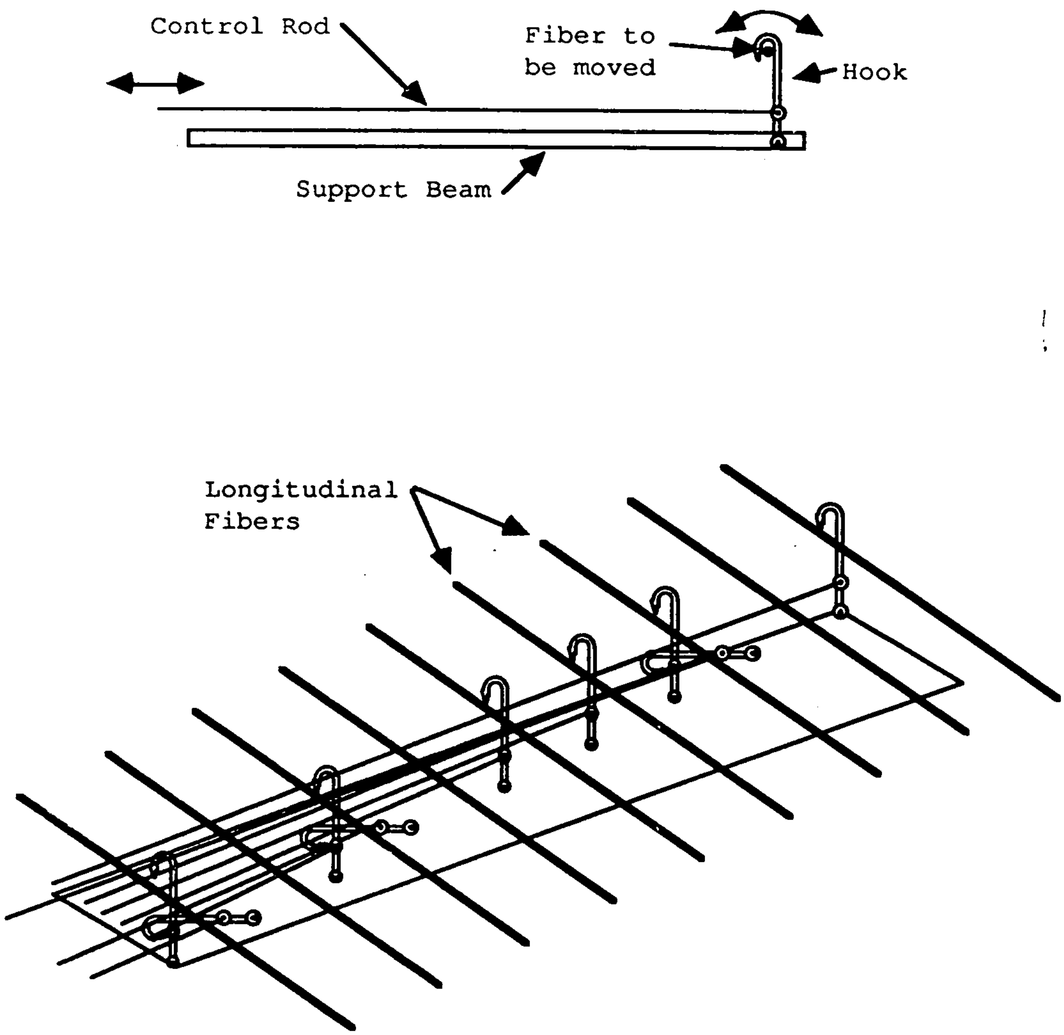


Figure 29. Retractable Hooks

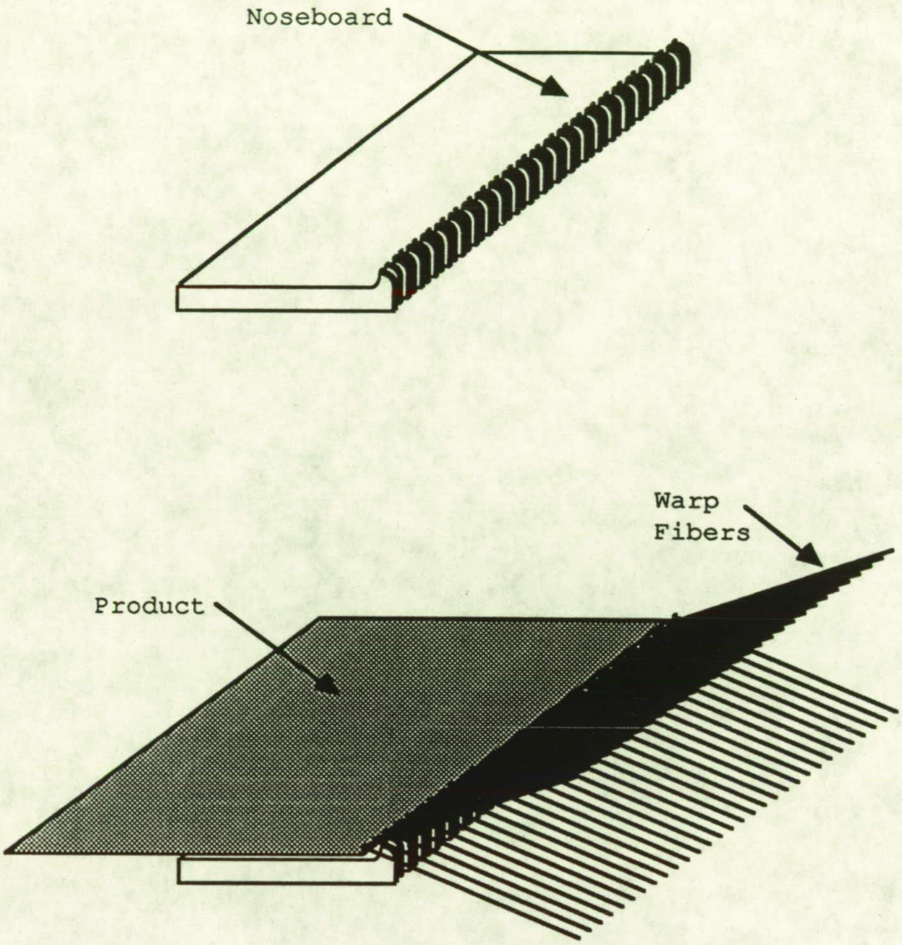


Figure 30. Noseboard Beat-up

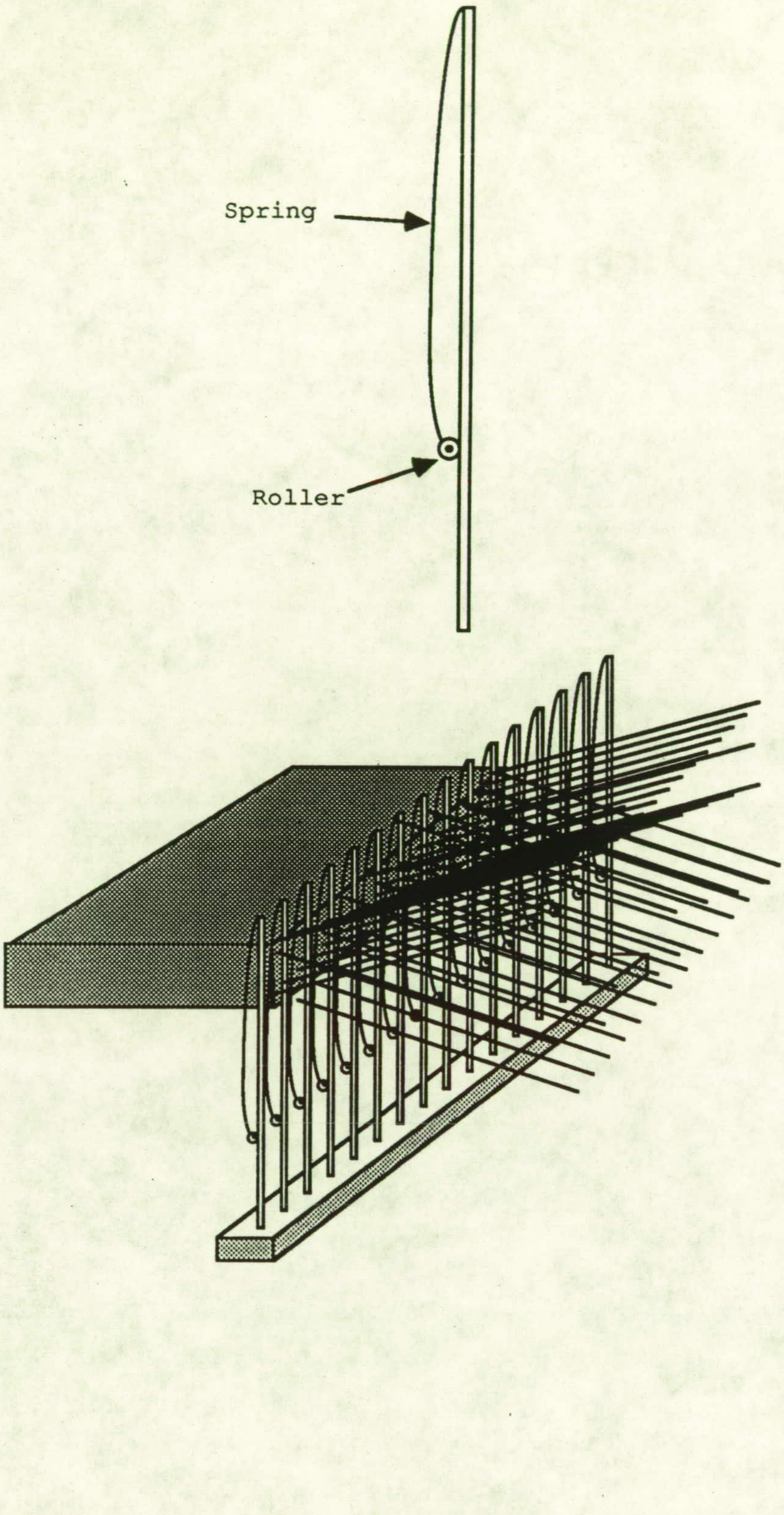


Figure 31. Sprung Reed

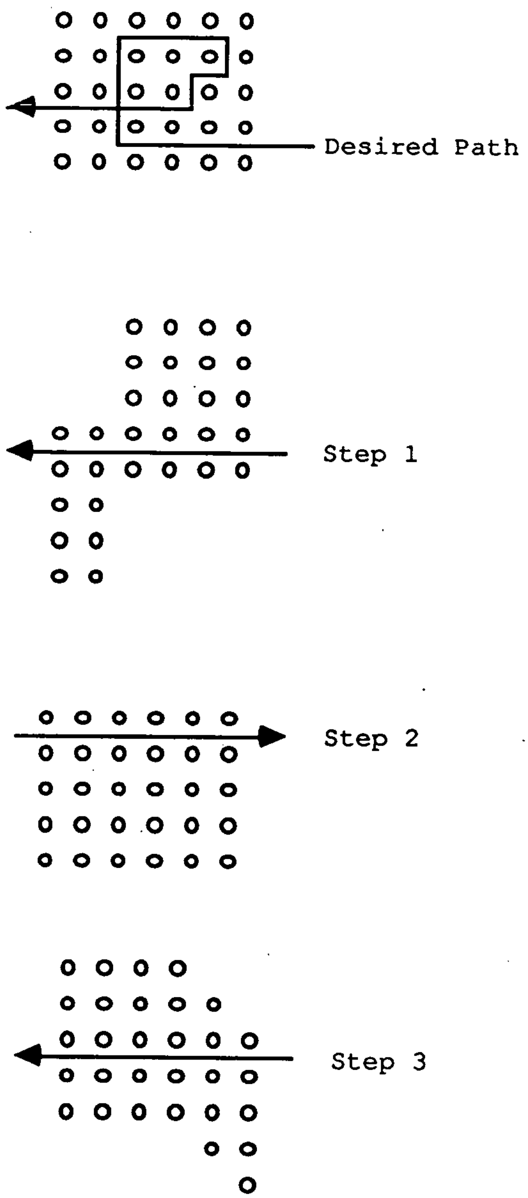


Figure 32. Column Shift

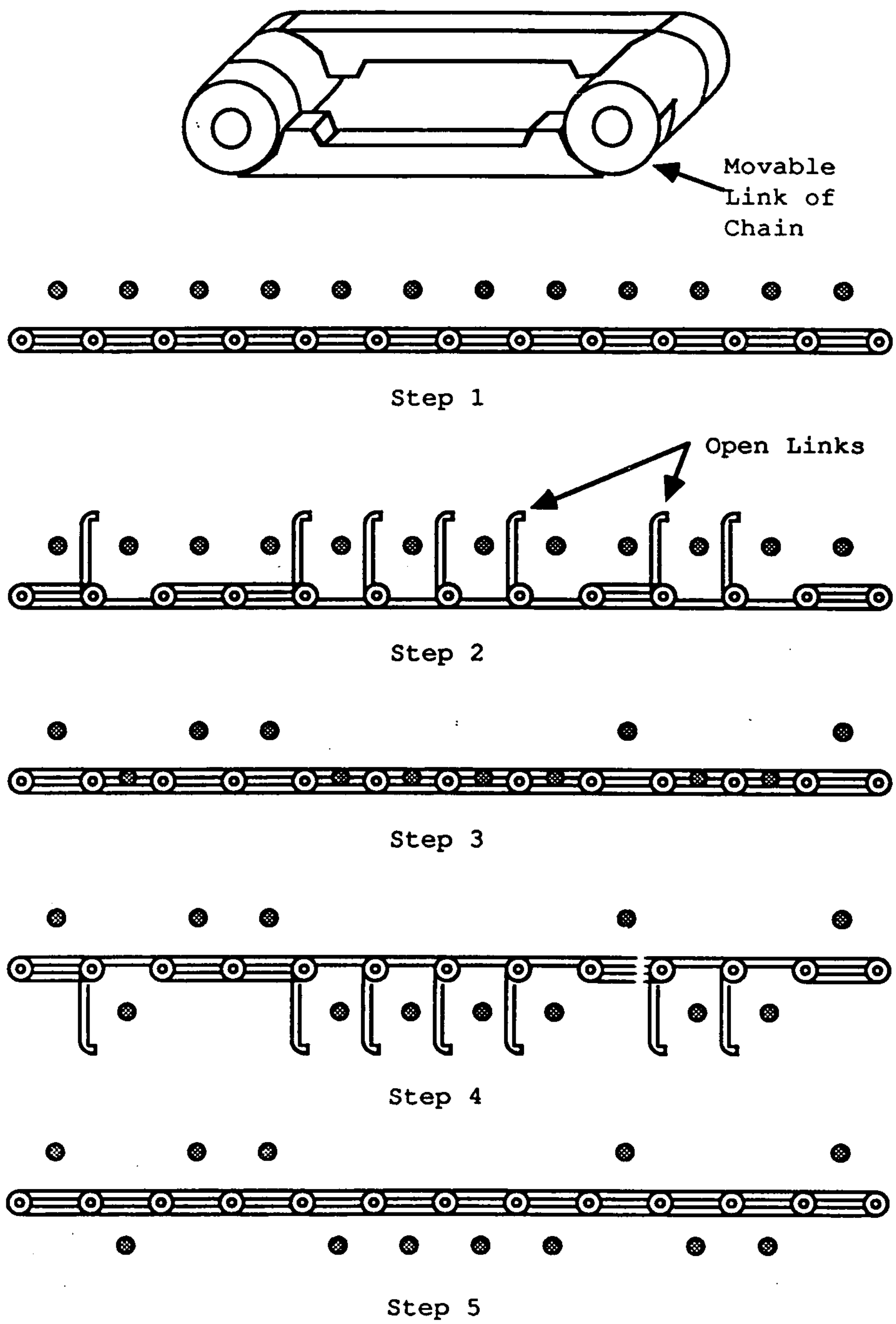


Figure 33. Movable Chain

CHAPTER 6
FEASIBILITY ANALYSIS

Feasibility Criteria

Once the initial concepts had been checked to make certain that each is physically possible to implement, each of the alternatives were examined to determine its feasibility as part of a production machine. The objective of the feasibility phase is to generate the set of discriminating criteria for feasibility, in terms of the manufacture of the composite structure, which will be used to determine the feasibility of each of the concepts.

First, the feasibility criteria had to be generated. There were six categories identified for the feasibility criteria as follows:

1. process control,
2. manufacturing flexibility,
3. machine requirements,
4. reliability,
5. safety,
6. ease of maintenance.

The first three categories, process control, manufacturing flexibility, and machine requirements, were by far the most important and revealed the limitations of several concepts. The remaining criteria in the topics of machine requirements, reliability, safety, and maintenance are all self explanatory. These criteria had no affect on the outcome of the feasibility analysis, but they can be used in final design work not presented in this paper. The eventual result of this feasibility study was the reduction of the number of concepts from thirty to eighteen. Each of the topics for feasibility will be discussed below.

Process Control

Process control covers the possible means by which the concepts would be actuated, such as stepper motors, solenoids, etc. The purpose of the feasibility criteria under this topic was to eliminate those concepts which would be too complex to control or actuate properly.

One important factor governing the process control is the number of controlled objects, or axes. There are three major types of actuators which we decided to consider: stepper motors, solenoids or switches, and pneumatic or hydraulic devices.

The simplest of these, solenoids or switches, would encompass any actuators which use electricity to switch between two states, on and off. Also, analog solenoids are also included in this category since they are relatively simple to actuate. The maximum number of these types of actuators that can be feasibly controlled by a computer for the implementation of the concepts is relatively high. Therefore we decided upon a maximum of 2000 solenoids or switches which corresponds to the number of fibers used to manufacture the product.

Stepper motors, or compu-motors are much more difficult to control, as well as being much more expensive. This category includes linear motors, which are even more expensive. Even though cost was not really a factor in this analysis, the relative costs among the different alternatives could not simply be ignored. Because of the relative complexity of these devices, we decided upon a maximum of ten stepper motors or similar devices.

In the remaining category, all pneumatic and hydraulic type devices are considered. These devices are usually binary in nature as well, however, they are not as simple to control. Also, most pneumatic devices, such as cylinders need considerable space for good operation, and are not as rapid as solenoids. Because of these reasons, we decided upon a maximum of ten pneumatic or hydraulic devices.

The criteria for position accuracy is to place a lower limit upon the accuracy that any part or fiber must maintain in order to fabricate

a product by a concept. If the required accuracy for the parts used in a concept is too restrictive then it may not be possible to implement. Also, the tight machining tolerances needed to hold the accuracy would cause excessive part cost. We decided that the minimum tolerance required on the parts of the machine was to be 0.005 inches. One exception which was made in this area was for cases in which existing parts could be used on the machine. There were several cases where existing textile machinery parts could be used to perform the desired tasks. Even though the parts were small, they are already mass-produced, making them inexpensive and reliable.

Control of the fiber tension is needed to aid in the control of the product characteristics, as described earlier. These characteristics include the fiber volume fraction and the braid angle. As stated in the target specifications, the concepts must be capable of varying the tension in the fibers from zero to ten pounds.

The final category under process control is the operating speed of at least three inches per hour. This was explained in the target specifications as the minimum production speed for any of the concepts.

Manufacturing Flexibility

The feasibility criteria topic of manufacturing flexibility deals with the product characteristics. These characteristics include the fiber angle variability, product size capabilities, variability of product geometry, and fiber combination pattern variability.

The fiber angle variability refers to the angle of the fibers in the final product. As described earlier, it would be advantageous to have complete variability over the orientation of all of the fibers as they form the product. This can facilitate a tightly packed structure when braiding or semi-braiding. We decided upon variability of thirty degrees for each of the fibers being used for braiding and semi-braiding.

The product size capabilities must be as large as stated in the target specifications. For flat panels and similarly shaped objects, the prototype size for the product will be twelve inches in width. This will increase to as much as twelve feet when production is considered. For thicker sections such as structural shapes, the prototype size for the product will be four inches square. This will increase to as much as twelve inches square when production is considered.

Each of the concepts were evaluated to determine how many of the product geometry types, defined earlier, that it could produce. Inability to produce all of the different geometry types is not reason to eliminate any one concept. However, the final concepts which are chosen must be capable of producing all of the geometry types.

The same can be said of the fiber combination patterns. If any one concept is incapable of producing all of the fiber combination patterns, there must be some other concept which will in the final set of choices.

Machine Requirements

Machine requirements consider the size the final machine and its parts, as well as other factors which directly relate to the design of individual components of the machine. In this category there are two main criteria: maximum fiber package size, and restrictions on concept scale-up.

The maximum fiber package size is a limitation upon the size of a carrier or fiber package which will be moved on the machine. Most conventional fiber packages range in size from nearly four inches in diameter to the size of a spool of sewing thread. In most cases which we considered, automatic tensioning and slack take-up were required as a part of the fiber packages. For this reason, the maximum size of the

fiber package was chosen to be one inch in diameter by six inches long. This size is a result of a compromise between having a large fiber package which is easy to make and maintain, and a small one which can pass other fiber packages easily. The restriction on the package size is to help minimize the machine size required to produce a composite structure.

The concept scale-up restriction is a criteria pertaining to the size and complexity of a proposed concept. The proposed concepts are to produce test specimens of only approximately four inches square. But the concept must posses the ability to be scaled up to full production size, of up to twelve inches square for complex shapes and twelve feet wide for flat sheets, without any problems in the overall machine size or complexity.

Reliability

The reliability of the machine(s) used to produce the three-dimensional composite structures must be reliable if profitable production rates are to be achieved. Though we considered applying strict numerical requirements to this subject, the final measure of reliability will depend upon the detailed aspects of the final design. We decided that an overall reliability rating for the machine should be at least 99 percent, meaning that under average conditions, the machine would operate 99 percent of the time.

Safety

Again, there are many factors governing the safe operation of any machine which are entirely dependent upon the details of a final design. Also, there are many safety codes governing the protection of workers near such machinery. We felt that the existing industry standards and codes for worker protection would be a logical starting point for making the designs safe. Additional measures could then be added concerning any additional risks.

Maintenance

Any machine which is used in the production of a product must be relatively easy to maintain if production is to be consistent. Because of this necessity, there must be allowances made for the ease with which the machine can be accessed and repaired. Also, the amount of time between scheduled maintenance operations should be mad as long as possible. Some examples of the requirements in this topic would be to limit the amount of time required to replace the most difficult to access part which might fail. We chose a limit of twenty hours for three men to replace the least accessible part.

Tool requirements should not be expensive. Special purpose tools and equipment for the machine should be kept to a minimum. We determined that one percent of the total cost of the machine should be the maximum spent for special tools.

The frequency of required maintenance was divided into lubrication requirements, adjustment of mechanisms, and wear life of the parts. We chose lubrication intervals of eight hours (one shift). Any mechanism adjustments should only be required once per week. All of the parts which might be subject to wear should require replacement no more often than three months of continuous operation. The cost of such replacement should not exceed ten percent of the machine costs per year.

Again, these are merely guidelines for the development of the final design for the machine. However, these factors should be considered throughout the design of the machines. Though we did not apply these considerations as strict criteria for feasibility, they were considered when the final choices for the designs were made.

Application of Feasibility Analysis

The list of discriminating feasibility criteria were used to analyze the design concepts and eliminate the non-feasible concepts. This process was accomplished using feasibility matrices, Tables 5 and

6. The first matrix analyzes the concepts using the process control criteria. The concepts surviving this phase were then analyzed with the remaining criteria one topic at a time. For clarity only the important criteria are shown in the matrices.

The process control criteria eliminated three concepts. These three were the Fukuta braider, the Warp Switcher, the Pivot braider, and the Bias Weave Hook Pass. The Fukuta braider and the Pivot braider were eliminated due to the excessive number of axes that would need to be controlled. The Fukuta braider had four rotary positions and a gripper mechanism at each turnstile, and even for a small machine hundreds of rotators could be required. This results in too many axes to control. The Pivot braider had two degrees of freedom at each fixed fiber location and then there would be several motorized fiber package carriers driving between the pivoted fixed fibers. This also yields to many controlled axis for even a small part. The Warp Switcher and the Bias Weave Hook Pass were eliminated because of the high position accuracy of the fibers and hooking system that was necessary for proper fiber path control in each method.

The remaining feasibility criteria eliminated eight more concepts. These were the Moveable Chain , the Helical Reed, the Two-Step Braider, the Magnaweave, the Tri-axial, the Noseboard Beat-up, the Concentric Ring Braider, and the Cam Beat-up. The reason for the elimination of the Moveable Chain is the machining tolerances that would be needed to produce the mechanism and its questionable speed. The Helical Reed, the Two Step braider, the Magnaweave, the Tri-axial, the Concentric Ring Braider, the Noseboard Beat-up, the Separate Warp Supplies, the Bluck Braider, and the Cam beat-up all failed the manufacturing flexibility criteria. All nine of these concepts failed because they did not allow for the flexibility of the fiber pattern and/or the flexibility of the product geometry.

This feasibility phase started with thirty concepts consisting of both main and support concepts. At the end of this analysis there still

remained eight main concepts and eight support concepts for a total of sixteen concepts. The feasibility study not only reduced the number of concepts using the discriminating criteria, it also gave a clearer view of the critical qualities that a feasible concept must posses.

Feas. Criteria \ Concept	Farley Bias Needle	Inflat. Boot	Bluck Braider	Fukuta Braider	2-Step Braider	Farley Braider	Magna-weave	Triax. Doweave	King 3-D Loom	AYPEX	Movable Chain	Sprung Reeds	Cam Beat-up	Rib Braider	Warp Switcher
Numder of Control Axes	OK	OK	OK (1)	X	OK	OK (2)	OK	OK	OK	OK	OK	OK	OK	OK	OK
Positioning Accuracy	OK	OK	OK		OK	OK	OK	?	OK	OK	OK	OK	OK	OK	X
Fiber Tension Control	OK	N/A	OK (3)		OK	OK	OK	OK	OK (4)	OK (4)	N/A	N/A	OK	OK	
Operating Speed	?	OK	?		OK	OK (5)	OK	OK	?	?	?	OK	OK	?	

Feas. Criteria \ Concept	Jaquard Heald	Retract. Hooks	Nose Board	Cantil. Healds	Bias Wv. Belt	Florent. Heald	Pivot Braider	Bias Wv. Hook Pass	Separate Warps	Bias Ins. Needle	Helical Reed	Hex Track	Hex Braider	Column Shift	Conc. Ring Bdr.
Numder of Control Axes	OK	OK	OK	OK	OK	OK	X	OK	OK	OK	OK	OK	OK	OK	OK
Positioning Accuracy	OK	OK	OK	OK (6)	OK (6)	OK		X	OK (6)	OK (6)	OK	OK	OK	OK	OK
Fiber Tension Control	OK	N/A	N/A	N/A	OK	OK			OK	OK	OK	OK	OK	OK	OK
Operating Speed	OK	?	N/A	?	OK	OK (5)			OK (5)	OK	OK	OK	OK	OK	OK

1. If solenoids are used 2. Less than 2000 free yarns 3.Passive 4. Not individually 5.Slow 6. Close

Table 5. Feasibility Matrix 1

Feas. Criteria \ Concept	Farley Bias Needle	Inflat. Boot	Bluck Braider	Fukuta Braider	2-Step Braider	Farley Braider	Magna-weave	Triax. Doweave	King 3-D Loom	AYPEX	Movable Chain	Sprung Reeds	Cam Beat-up	Rib Braider	Warp Switcher
Machine Tolerances	OK (1)	OK	OK		OK	OK	OK	OK	OK	OK	X	OK	OK	OK	
Fiber Pattern	OK (1)	OK	OK		X	OK	X	X	OK	OK		OK	X	OK	
Product Geometry	OK	OK	X			OK			OK	OK		OK		OK	
Scale-up	OK	OK				OK			OK	OK		OK		OK	

Feas. Criteria \ Concept	Jaquard Heald	Retract. Hooks	Nose Board	Cantil. Healds	Bias Wv. Belt	Florent. Heald	Pivot Braider	Bias Wv. Hook Pass	Separate Warps	Bias Ins. Needle	Helical Reed	Hex Track	Hex Braider	Column Shift	Conc. Ring Bdr.
Machine Tolerances	OK	OK	OK	OK	OK	OK			OK	OK	OK	OK	OK	OK	OK
Fiber Pattern	OK	OK	X	OK	OK	OK			X	OK	X	OK	OK	OK	X
Product Geometry	OK	OK		OK	OK	OK				OK		OK	OK	OK	
Scale-up	OK	OK		OK	OK	OK				OK		OK	OK	OK	

1. Not for all geometries

Table 6. Feasibility Matrix 2

CHAPTER 7

PRELIMINARY DESIGN ANALYSIS

Now that the feasibility analysis had been completed, the remaining concepts could be evaluated for preliminary design possibilities. The remaining concepts are repeated in Tables 7 and 8 for convenience.

Table 7

Main Concepts:

1	Farley Bias Needles
2	Bias Weaving Belt
3	Bias Insertion Needles
4	Farley Braider
5	King 3-D Loom
6	AYPEX
7	Hex Track
8	Hex Braider

Table 8

Support Concepts:

1	Inflatable Boot Beat-up
2	Sprung Reeds
3	Rib Braider
4	Jaquard Heald
5	Retractable Hooks
6	Cantilevered Heald
7	Florentine Heald
8	Column Shift

At this point, it was decided that an examination of the necessity for some of the support concepts was needed. Several of the main

concepts for which the remaining support concepts were developed no longer existed. Each main concept was examined in more detail.

Concept Analysis

Farley Bias Needles

This concept, as explained earlier, was conveyed to us by NASA. It involves insertion of bias fibers into a woven or semi-woven structure using needles which pass through a single layer of warps. Several applications were suggested for this concept. One application would be for woven products. More than two layers of woven structure cannot be accommodated by this concept, however, since the needle mechanism prevents shedding of the warps if between layers. It was suggested that by allowing the needle holders to be extracted from the sides of the structure, this limitation would be eliminated. We found this not to be the case, however, since the trailing bias fibers from the needles into the product would then be trapped by the warps. This would not produce the correct orientation for the bias fibers.

For Semi-woven products, the Farley Bias Needles can be used for multi-layered structures. This is because the warp fibers are always parallel to each other. The needle holders can be left between the layers of warp fibers. Two sets of needle holders could be used per layer to facilitate two different bias fiber directions within each layer. Also, for relatively thin sections, the through-the-thickness fibers could be incorporated into the structure with additional sets of needles.

One desirable feature of this method is the ease of actuation of the concept. Each needle has only two positions. This makes some type of electrical switching arrangement, such as solenoids or solenoid

controlled pneumatics, a likely candidate for actuation. This can accommodate many needles (2000 for the purposes of this study).

One difficulty with this concept is that the beat-up of the weft fibers into the structure cannot be performed with a conventional reed. The needle holders do not allow a reed to pass between the warps. Also, there is some doubt that a conventional reed could properly beat the bias fibers into place without damaging them. The suggested solution to this problem was the Farley Inflatable Boot concept which had not been eliminated thus far. As explained earlier, the Farley Inflatable Boot uses a cantilevered beam with an inflatable boot attached to one edge to perform both the weft insertion and the beat-up. Upon examination of this concept, we decided that the bias fibers would be positioned better with little likelihood of damage. There was some question as to the ability of the boot to properly insert the weft fiber. We ran some tests using a small rod and a mock-up of the shed area. There was a strong tendency for the weft fiber to follow the boot back out of the shed, because the boot spread the warps apart too much for the weft to wedge in place. One possible solution to this problem would be the incorporation of a thin, solid ridge on the surface of the boot to push the weft fiber in place. This ridge would have to be quite narrow to work properly.

Another possible solution to the beat-up problem is the Sprung Reed concept. This concept uses thin comb-like structures with a known spring constant to apply a force to the weft, much like a conventional reed. The springs are completely withdrawn from the shed area when not in use. The advantage of this concept is that a known force is applied, and cannot be exceeded. This will avoid damaging the bias fibers as they are pushed into place. Also, the springs could be designed to apply a known applied force over a large area, such as a thick cross-section. This concept would not perform the insertion of the weft fibers. That would have to be done by some other means, such as air jet insertion.

Bias Weaving Belt

The Bias Weaving Belt concept was originally developed as a possible solution to the beat-up problem in woven structures with bias fibers. By placing bias fiber sources along the belt to supply each of the fingers with a fiber, the concept becomes relatively independent of all of the support concepts. The Bias Weaving Belt is best suited to single-layer structures. This is because of the limited access to the fibers in the composite structure. Since only two bias fiber directions can be accommodated, one on each side of the structure, the concept is not well suited for thicker sections.

The primary advantage of this method is its speed and simplicity. For most applications, where all of the fingers need to be actuated simultaneously, only one actuator is needed for all of the fingers. The fingers could be independently actuated with solenoids, but the solenoids would have to remain stationary with respect to the structure to facilitate electrical connections. This concept is probably the most rapid for the insertion of bias fibers, since the entire belt can be indexed by the desired amount in just one motion.

Bias Insertion Needles

This concept involves the use of both stationary and movable tubes, or needles, which move with respect to each other to intertwine the fibers. It is well suited to the insertion of bias fiber into both single layer and multi-layer structures. It can accommodate both weaving and semi-weaving fiber combination types, as well, even for thick cross-sections. This is because the tubes perform the actual shedding of the warp and bias fibers after the area in which the bias fibers cross the warp fibers. Because of this geometry, many layers of warp fibers can be woven with bias fibers in every layer, if desired.

This concept does suffer from the disadvantage that conventional beat-up cannot be used. The transverse motion of the bias fibers

cannot be performed if a conventional fixed reed is used. The Farley Inflatable Boot or the Sprung Reeds could be used for this purpose, however.

Farley Braider

The Farley Braider concept, as suggested to us by NASA, involves the motion of independent fiber sources which are self actuated with stepper motors to pass angled fibers around either stationary longitudinal fibers or each other. One obvious advantage of this concept is its ability to create any path through a set of longitudinal fibers. This is a great advantage in flexible manufacturing. For structures that use relatively few angled fibers, this method can be practical to actuate. We determined that a more practical implementation might be to use less expensive DC motors to provide propulsion for the tractors and use proximity sensors to locate the tractors on the rotators. This is both less expensive, and more reliable than using the stepper motor's rotation to calculate the position of each tractor. Also, the electrical signals used to drive stepper motors must be exceptionally free of electrical noise. This would be extremely difficult to achieve with the required sliding electrical contacts.

Another possible area of improvement would be the reduction or elimination of the electrical sliding contacts between the tractors and the rotators. By using DC motors for the tractors instead of stepper motors, only one sliding contact is needed instead of four or five. We could not determine a practical alternative method for sending power to the motors in order to eliminate the electrical contacts altogether.

The closest thing which could be devised would only work if the fibers used to create the composite structure were conductive. If that were the case, the entire braiding bed could be connected to an oscillating voltage. Each tractor would receive power from the linear

bearing it rests upon. The fibers for the composite structure could serve as the ground. The frequency of the voltage could be used to control the motion of the tractors. Each tractor motor would be sensitive to one frequency band, and would be controlled by variations in this frequency. Complex electronics are required for the decoding of the oscillating voltage for each motor, but a similar scheme has been used for controlling model trains for several years. The hardware to implement this scheme is currently being produced.

One additional variation of the Farley Braider was devised. If each of the rotators could be made into a small linear bearing, the propulsion of the tractors could be accomplished without having to supply power to the tractors at all. Each tractor could be built upon a permanent magnet which would be acted upon by the linear motors within the rotators. We found no commercially available hardware to implement this scheme, but we felt that with some development, it could be very practical, as well as reliable.

One persistent problem with the creation of thick cross-sections with fibers has been the inability to pack the interior fibers into the structure sufficiently to provide the necessary rigidity. One possible solution for this is to allow the angle of the angled fibers to be varied enough to wedge the fibers closer together within the structure. This is what is commonly done in the manufacture of ropes and cables. Another possibility is the use of some sort of beat-up mechanism, similar to what weaving processes use.

The Sprung Reed concept described earlier is well suited to this task. The springs may be designed to apply a known force across the thickness of a cross-section. Also, the individual springs can be made very small, so that they may be inserted between closely spaced longitudinal fibers.

King 3-D Loom

As described earlier, the King 3-D loom can be used to create semi-braided structures with thick cross-sections. The only remaining task to make this concept usable for a variety of structures is to implement some method for passing angled fibers through the longitudinal fibers. This can be accomplished with the Column Shift concept described earlier. This could be used to move the ends of the fibers attached to the top of the frame. Fiber supplies could then be passed through the structure to create the desired pattern.

Any pattern can be made in this way with the column shift. The primary advantage for the method is the ease of actuation of the concept. The only possible problem with this method is the large amount of slack which must be removed from the angled fiber at the direction of the fiber source is reversed through the structure. In cases where the path crosses upon itself, tangling of the angled fibers may occur. This could be eliminated to a large extent if a suitable take-up mechanism could be incorporated into the fiber source.

To accomplish the beat-up, the Sprung Reed concept could be implemented here, as well. Two sets of sprung reeds could be used to form a crossing network of springs. The two reeds would probably have to be actuated independently to work effectively, however.

AYPEX

The AYPEX concept is suitable for thick or thin cross-sections. It is capable of producing any desired path through a set of longitudinal fibers, or any desired combination of angled fibers. The largest disadvantage of the concept is the required complexity. For a reasonably complex pattern, many exchanges of fibers may be required. Many fibers will have to be moved to produce the motion of one fiber. Even if relatively few fibers are used as angled fibers, many exchanges may be necessary.

When this concept was relayed to us by NASA, no practical method had been devised for moving the fiber sources from one rotator to another. After examination of the concept, we devised one relatively simple method wherein solenoids could be mounted on the rotators to push the fiber sources from one rotator to another. This would be relatively inexpensive and easy to implement. Another possibility is using electromagnets within the rotators to propel the fiber sources in a similar manner, eliminating the solenoids. We found no existing application of this concept, however.

When the original AYPEX concept was communicated to us, a prototype application existed. This prototype was simplified in many ways. The largest simplification was that the fibers could only be exchanged in rows or columns. A set of hooks were used to exchange all of the fibers in one row or column. Our Retractable Hooks concept evolved from this. It was the goal of this concept to allow the exchange of only some of the fibers in a given row. This could be accomplished by having hooks which could be retracted if not needed. This would allow the full flexibility of the AYPEX method to be realized without using a large number of control devices.

Like the other devices capable of producing thick cross-sections, a suitable beat-up device is required. The Sprung Reed concept would be applicable for this device as well.

Hex Track

The Hex Track concept evolved from the Farley Braider concept after realizing that the motion of the tractors of the Farley Braider was interrupted every time a change in direction was needed. This is one of the advantages of the Hex Track concept. For any of the tractors, a continuous path may be created by aligning the rotators properly. Also, at each rotator, only two possibilities exist. Either the tractor turns right, or it turns left. As a result, the control of

the individual rotators is relatively simple. Each rotator has only three possible positions. This could be accommodated with a single analog rotary solenoid, or with two binary rotary solenoids in series. All of the previous discussion concerning transmitting the power and control to the motors for the Farley Braider applies here, as well.

Another advantage of the Hex Track concept is its hexagonal geometry. This geometry can be made quite versatile if different sized rotators are used. A geometry similar to that of a geodesic dome structure could be used to allow the Hex Track to be used within a spherical surface. This could be used to control both the braid angle for tightening the composite structure, and the overall size of the machine itself.

Like the other devices capable of producing thick cross-sections, a suitable beat-up device is required. The Sprung Reed concept would be applicable for this device as well.

Hex Braider

The Hex Braider is yet another evolution of another concept. By modifying the rotators and placing additional rotators in the hexagonal spaces in the Hex Track, the Hex Braider is realized. The primary advantage of the configuration of this concept is the compactness of the design. Note that each rotator has five entry points and only one exit. This allows only converging paths, so that the tractor's direction can be controlled passively.

One disadvantage of this concept is that each rotator has six possible orientations. This would be more difficult to implement. Analog rotary solenoids would be most likely to be practical, though three binary rotary solenoids could be used in series for each rotator. Again, a continuous path can be made for each of the tractors, which allows the tractors to be moved continuously.

Like the other devices capable of producing thick cross-sections, a suitable beat-up device is required. The Sprung Reed concept would be applicable for this device as well.

Support Concept Evaluation

From examination of the different main concepts and their required support concepts, we decided that the Jaquard Heald, the Cantilever Heald, and the Florentine Heald were no longer needed. The one possible exception to this would be using the Cantilever Heald concept to assist in the shedding of the warp fibers in the Bias Insertion Needles concept. They might be used to produce some of the sheds where the warp fibers from opposite sides of a thick cross-section would be crossed. This would allow shorter needles to be used.

This leaves the Farley Inflatable Boot Beat-up for the Bias Insertion Needles, the Sprung Reeds for all of the main concepts except the Bias Weaving Belt, the Retractable Hooks for the AYPEX concept, the Column Shift for the King 3-D Loom, and the Rib Braider. The Rib Braider is a special case. This concept could be used with any of the main concepts mentioned above. A rib could be attached to any structure which contains longitudinal fibers. It can also be made into a wide variety of shapes by changing the braid pattern of the rib braider or moving it transversely across the side of the product as it is formed.

Comparison of Remaining Alternatives

At this point, it was decided to compare the capabilities of the different alternative concepts so that the most useful concept(s) could be chosen. Table 9 shows the capabilities of each of the concepts in terms of product geometry types and fiber combination types. Note that the Farley Braider, AYPEX, Hex Track and Hex Braider can produce all of the fiber combination types and all of the product geometry types. This

is reflective of the statements made earlier; that a braider can weave. This does not necessarily mean that any of these concepts are the best for all of the product types.

At this point, it was decided that more than one concept would be necessary for the fabrication of all of the geometry and fiber combination types. While this may seem obvious, remember that one of the reasons for remaining ambiguous about which types of machines would be used for different products was to reduce the possibility of being limited by conventional processes. After reaching this conclusion, we decided that the above concepts would be best suited for braiding and semi-braiding, and the King 3-D Loom with Column Shift would be best suited for semi-braiding. This left the Farley Bias Needles, Bias Weaving Belt, and the Bias Insertion Needles for the weaving and semi-weaving patterns.

Examining Table 9 again reveals that only the Bias Insertion Needles can accommodate all of the product geometries with both weaving and semi-weaving. This makes the Bias Insertion Needles the most versatile of the concepts for these fiber combination types. The Farley Braider, AYPEX, Hex Track and Hex Braider can all produce all of the product geometries with both braiding and semi-braiding. Further analysis was needed to determine which was best.

The next step was to perform some decision analysis. Tables 10 through 12 show the decision matrices which were used to score the different alternatives. Note that all eight of the alternatives were examined, even though only four were necessary. This was done to check our conclusions. Table 10 shows how the alternative concepts were rated for variation of product geometry. The scores which were used to rate the satisfaction of concepts were based upon our opinion of the usefulness of being able to create the given product geometry. Single layered products are in widespread production now, so it was weighted only 0.05. Multi-layered products with constant thickness and cross-section are made now in limited instances, and are more easily

made than varying cross-section and thickness, so it was given a higher weighting of 0.20. The remaining 0.75 points were divided equally among the other three product geometry types. For the percent satisfaction of the alternatives, five values were allowed; 0, 25, 50, 75 and 100 percent satisfaction. The scores were calculated as shown in the table.

Table 11 shows how the concepts were rated on variability of fiber combination types. For this, the weights were 0.25 for each pattern. The different alternatives were scored like for the product geometry types. This is shown in the table.

Table 12 combines the results from Tables 10 and 11 with ratings for the production speed and the overall simplicity of the design. For the purposes of this study, we felt that the ability to produce a wide variety of product geometries was most important; as important as everything else combined. We weighted this at 0.5. Variability of pattern was also considered important, so we weighted this 0.3. Production speed, which is not very important in aerospace applications, was rated at 0.1. Note that we did not actually attempt to predict the actual production speed of any of the concepts, but made judgements based upon the relative performance of the concepts. The remaining 0.1 went to the overall simplicity of the design. This encompasses several things. The simplicity of a design has a bearing upon the reliability and efficiency of the design. This category was an opportunity to bring all of the opinions about both simplicity of operation and machine efficiency into play. The scores in this category also reflected our overall opinions about how well the concepts would perform the required tasks.

Once the overall scores were calculated, our previous observations were confirmed to some degree. The Bias Insertion Needles received the highest score of the weaving concepts. Unfortunately, the Farley Braider, AYPEX, Hex Track and Hex Braider all received the same final score. This reflected our earlier statements, but did not help us to reach a decision. We re-examined each of the four concepts again to

help us decide upon one for our recommendations. We understood that we were not required to choose only one solution, but we felt that it would be best to choose a possible path for future research. This would require a decision as to which alternatives were best.

We found two topics that would help us to reach a decision. The first of these was the complexity of the actuation. The Farley Braider requires that each rotator be capable of reaching four positions. This is also true of the AYPEX concept. The Hex Track requires that only three positions be reached. The Hex Braider requires six positions for each rotator. Also, the AYPEX required additional actuation of some sort to move the fiber sources between the rotators. This topic eliminated the AYPEX and the Hex Braider concepts.

The other topic was operating efficiency. Recall that the Farley Braider requires the tractor to stop before the rotator can be turned to change the direction of motion of the tractor. This not only slows the speed of production, but it represents additional operations which are required to accomplish the production. The AYPEX concept also requires a large number of stop-and-go operations which are inefficient. As already discussed, a large number of motions are required for even simple patterns. The Hex Track and Hex Braider do not require the tractor to stop in order to change direction. Also, only those rotators directly involved in the path of the angled fibers are controlled. Thus, the Farley Braider and AYPEX concepts can be eliminated by this topic.

After examination of the efficiency and controllability of the concepts, the Hex Track was decided to have a slight advantage over the other three concepts. Remember, of course, that there are numerous factors which can be applied to the evaluation, and the ones which we chose were not necessarily the only ones. We felt that all four of the surviving braiding concepts were feasible, and could be implemented with success. Which one would actually be best depends upon the relative importance of all of the factors mentioned.

A Farley Bias Needles
B Bias Weaving Belt
C Bias Inserter Needles
D Farley Braider
E King 3-D Loom With Column Shift
F Aypex
G Hex Track
H Hex Braider

	Weaving	Semi-weaving	Semi-braiding	Braiding
Single layer	A,B,C,D,E,F,G,H	A,B,C,D,E,F,G,H	D,E,F,G,H	D,F,G,H
Multi-layer	C,D,E,F,G,H	A,C,D,E,F,G,H	D,E,F,G,H	D,F,G,H
Multi-layer w/ varying thickness	C,D,E,F,G,H	A,C,D,E,F,G,H	D,E,F,G,H	D,F,G,H
Multi-layer w/ stiffners	A,C,D,E,F,G,H	A,C,D,E,F,G,H	D,E,F,G,H	D,F,G,H
Complex Geometry	C,D,E,F,G,H	C,D,E,F,G,H	D,E,F,G,H	D,F,G,H

Table 9. Capabilities of Concepts

Concept \ Criteria	Single Layer	Multi-layer	Varying Thickness	With Stiffners	Complex Geometry	Score
Weight	0.05	0.20	0.25	0.25	0.25	
Farley Bias Needles	100 / 5	75 / 15	50 / 12.5	25 / 6.25	0 / 0	38.75
Bias Weaving Belt	100 / 5	0 / 0	0 / 0	0 / 0	0 / 0	5.00
Bias Insertion Needles	100 / 5	100 / 20	75 / 18.75	50 / 12.5	0 / 0	56.25
Farley Braider	75 / 3.75	100 / 20	100 / 25	100 / 25	100 / 25	98.75
King 3-D With Column Shift	75 / 3.75	100 / 20	75 / 18.75	100 / 25	100 / 25	92.50
AYPEX	75 / 3.75	100 / 20	100 / 25	100 / 25	100 / 25	98.75
Hex Track	75 / 3.75	100 / 20	100 / 25	100 / 25	100 / 25	98.75
Hex Braider	75 / 3.75	100 / 20	100 / 25	100 / 25	100 / 25	98.75

Table 10. Subordinate Decision Matrix 1

Criteria / Weight / Concept	Weave		Semi-Weave		Semi-Braid		Braid		Score
Weight	0.25		0.25		0.25		0.25		
Farley Bias Needles	25	6.25	50	12.5	0	0	0	0	18.75
Bias Weaving Belt	25	6.25	25	6.25	0	0	0	0	12.5
Bias Insertion Needles	75	18.75	75	18.75	0	0	0	0	37.5
Farley Braider	75	18.75	75	18.75	100	25	100	25	87.5
King 3-D With Column Shift	100	25	100	25	100	25	0	0	75
AYPEX	75	18.75	75	18.75	100	25	100	25	87.5
Hex Track	75	18.75	75	18.75	100	25	100	25	87.5
Hex Braider	75	18.75	75	18.75	100	25	100	25	87.5

Table 11. Subordinate Decision Matrix 2

Concept \ Criteria	Variability of Geometry		Variability of Pattern		Operational Speed		Overall Simplicity		Score
Weight	0.5		0.3		0.1		0.1		
Farley Bias Needles	38.75	19.375	18.75	5.625	75	7.5	50	5	37.5
Bias Weaving Belt	5	2.5	12.5	3.75	100	10	100	10	26.25
Bias Insertion Needles	56.25	28.125	37.5	11.25	75	7.5	50	5	51.875
Farley Braider	98.75	49.375	87.5	26.25	25	2.5	25	2.5	93.125
King 3-D With Column Shift	92.5	46.25	75	22.5	50	5	50	5	93.75
AYPEX	98.75	49.375	87.5	26.25	25	2.5	25	2.5	93.125
Hex Track	98.75	49.375	87.5	26.25	25	2.5	25	2.5	93.125
Hex Braider	98.75	49.375	87.5	26.25	25	2.5	25	2.5	93.125

Table 12. Main Decision Matrix

CHAPTER 8

SUMMARY AND RECOMMENDATIONS

Throughout this design exercise, we considered and developed many different alternative concepts for the fabrication of three-dimensional composite fiber structures. This required the evaluation of the needs of NASA, as well as the possible future needs for the aerospace industry. Objectives were set for the semester which included evaluation of the concepts, and delineation of the important factors governing each design. In addition, we were able to choose two preliminary design alternatives which would be the most likely candidates for future development. These concepts are the Bias Insertion Needles, and the Hex track. Three other concepts were determined to be possible candidates for future research. These concepts are the Farley Braider, AYPEX concept, and the Hex Braider. These concepts could also be developed in the future, depending upon the needs of NASA and the aerospace industry as a whole.

The Bias Insertion Needles concept is useful for all of the product geometry types described herein, with either weaving or semi-weaving fiber combination patterns. The concept is versatile enough to allow any cross-section to be created with these fiber combination patterns. The means for actuation of the concept are relatively straightforward. The needle tracks can be rotated using a simple pneumatic cylinder arrangement. The needles can be indexed using a stepper motor and worm drive for linear motion. The major area which will need additional research will be the insertion and removal of the needles from the ends of the needle tracks. This could present difficulties for positioning and complex motion generation. We feel that this should not present a major difficulty, however.

The Sprung Reeds support concept would be the best method for beating up the composite fibers, especially for thick or complex

cross-sections. Air jet weft insertion could also be used for the placement of the weft fibers prior to beat-up.

The Hex Track concept is capable of creating any of the product geometries in any of the fiber combination patterns. The concept is best suited for the braiding and semi-braiding fiber combination patterns. This concept is versatile enough to create any cross-section which might be needed, including hollow cross-sections. The rotators are relatively simple, with only three necessary orientations for each. Also, not all of the rotators need to be actively controlled to create the product. The track created by the rotators is continuous, allowing efficient, continuous operation of the tractors. The geometry of the track allows adaptation of the rotators to fit into a spherical surface. This is advantageous since the braid angle can be controlled to an extent with this configuration. Also, the overall size of the production machine could be made smaller.

The remaining area for development of this concept is the method by which the tractors will be propelled and controlled. The most easily implemented method would be to use DC motors for the propulsion, and proximity sensors to detect the position of the tractors. The necessity of electrical contacts for delivering power to the tractors could be a source of difficulty. Some of the alternative methods for propulsion devised during our research can eliminate this, but will require the development of new technology.

In summary, a great deal of effort was put into the development of new and existing concepts for the fabrication of three-dimensional composite structures. Many concepts were synthesized, but only eight concepts were determined to be feasible. These eight were evaluated more extensively to determine the strengths and weaknesses of each. Two of the concepts were chosen for likely candidates for future research, although others could have been chosen. This will depend upon the needs of the organization which will examine any future applications of these

concepts. These concepts should prove to be of great benefit to the aerospace industry as a whole in the future.